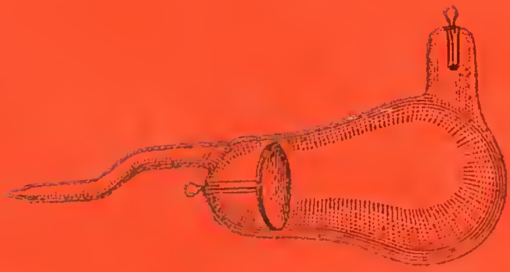
CHEMISTRY IN DAILY LIFE



PROF. LASSAR-COHN.

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CHEMISTRY IN DAILY LIFE

CHEMISTRY IN DAILY LIFE

POPULAR LECTURES

BY

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TRANSLATED BY

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WITH 21 WOODCUTS IN THE TEXT

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PREFACE

THIS book, which now appears in English, embodies the substance of a course of lectures delivered by Dr. Lassar-Cohn, Professor of Chemistry in the University of Königsberg, to a society in that town modelled on the celebrated *Humboldt Academy* of Berlin.

These lectures, and the publication of them in book form, caused quite a stir in German circles. And it is in the hope that they will prove at once interesting, instructive, and suggestive to English readers that I have prepared a translation at the request of the publishers.

That the lectures cover a great variety of topics will be evident from a glance at the *Table of Contents.* The method of treatment is eminently human and suggestive. The author shows that chemical phenomena are intimately bound up with our daily lives, and that whether we are conscious of it or not we are constantly carrying on chemical operations. He also brings home to us how chemical considerations play their part in those speculations regarding the physical universe that are suggested by each fresh discovery made by science.

Vague notions circulate in men's minds concerning chemistry. Some think the chemist is a man who compounds drugs and mixes pills; and others look on him as an astrologer of the modern sort. This book shows that the chemist is in a sense both of these, and much more than both; it causes the careful reader to realise the permeating nature of chemical knowledge, and it teaches him that chemistry is emphatically the most human, and for that reason the most fascinating, of the sciences.

The book can be followed intelligently by any reader who gives it a little care; no special technical knowledge is required.

The translation has been made from a copy of the original book kindly lent by the Author containing Dr. Lassar-Cohn's corrections and additions.

The very few additions made by the Translator are inclosed in square brackets.

M. M. P. M.

Cambridge, May 1896.

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CHEMISTRY IN DAILY LIFE.

LECTURE I.

Breathing.—Physics and chemistry.—The weight of the air.—Analysis of air.—Argon.—Ozone.—Difference between inspired and expired breath.—Maintenance of the warmth of the body.—Combustion.—Matches.—Yellow and red phosphorus.

In the lectures which begin to-day I hope to convince you that a foundation of chemical knowledge is needed for understanding many occurrences of everyday life. We shall see that there are many facts which have become so familiar to us by custom that we pay scarcely any heed to them, and seldom give ourselves the trouble of thinking about the more intimate relations of them.

Let us begin by considering an action which we perform constantly—the action, namely, of breathing. We speak of the duration of our lives as the time between our first and last breaths.

At once we are faced by the question, What do we breathe, and for what purpose do we breathe? Every one knows that we breathe the air which surrounds us. But what is this air ?

Here it is necessary to make a short excursion into the domain of physics, which is a branch of science that concerns itself with occurrences, such as the magnetisation of iron, wherein no change of material composition takes place. Chemistry, on the other hand, is that part of natural knowledge whose task it is to investigate events, such, for instance, as the rusting of iron, wherein changes of material composition do take place. When a piece of iron is magnetised, it is not changed internally or externally from its former condition, except that it acquires the power of attracting other small pieces of iron ; on the other hand, when iron rusts, it is changed into a brown substance which is something quite different from iron—for instance, it is not rigid like iron, but can be rubbed to powder between the fingers.

To return to our main theme. Is the air something which has an actual material existence, or is it only existent in our imagination ? For it cannot be asserted that any one possesses a sense-organ whereby he can discover the actual existence of air. We talk, indeed, of the heaviness of the air ; but I fancy there is scarcely one among those present who is able to determine accurately the weight of a definite quantity of air—say, for instance, the weight in kilograms of the air in the room wherein we are assembled.

We cannot directly convince ourselves that the air is heavy. We wave our hands to and fro in the air without any apparent hindrance ; we even move our whole bodies without trouble through the air. And although these facts, and many other similar facts, seem entirely to contradict the notion that air is heavy, nevertheless every one knows to-day that air weighs something. But this is only because every one has been accustomed from his youth to hear this property of air spoken of with absolute certainty.

If we consider a little, we shall find many other well established facts in the domain of natural science which no one doubts, although these facts cannot be demonstrated directly. For instance, every one admits that the shape of the earth is that of a sphere, although no proof of this has yet been found that can be grasped without much difficulty by lay minds.*

We are, however, in a better position in dealing with the case before us, inasmuch as we can easily convince ourselves of the weight, and hence of the material existence, of the atmosphere. For this purpose let us carry out a simple experiment.

The flask A (fig. 1) is placed on one pan of a balance, and the beam is brought into equilibrium by placing weights on the other pan. The special things to be noticed about this flask are, that the neck has been drawn out to a fine opening, that the air has then been pumped out of the flask by means of an air-pump, and that the neck has then been sealed by melting the glass; the interior of the flask is evidently cut off from the air outside. When I now break the end of the neck of the flask by means of pliers, the pan in which the flask rests sinks, although the flask cannot have been made heavier by cutting off the end of the neck. The cause of this occurrence is that air rushes into the flask through the opened neck, and the heaviness of this air is made visible to us by the descent of the balance-pan. If we know the capacity of the flask, and if we now place weights on the other pan till equilibrium is re-established, we can read off directly the weight of the air which has rushed into and filled the flask. Careful experiments have shown that one litre of air weighs 1·295 grams [one cubic foot weighs 564 grains].

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* The fact that at sea the tops of the masts of an approaching vessel are the first parts of her to be seen is often adduced as the simplest proof of the curvature of the earth's surface caused by the spherical form of the earth. Although the Greeks and Romans often observed the phenomenon in question, yet they did not draw the conclusion that the earth is spherical; but among them were many clear-headed men. The alleged proof is quite inconclusive of itself, and it came to the front only after the spherical form of the earth had been established on the basis of strictly scientific investigations.

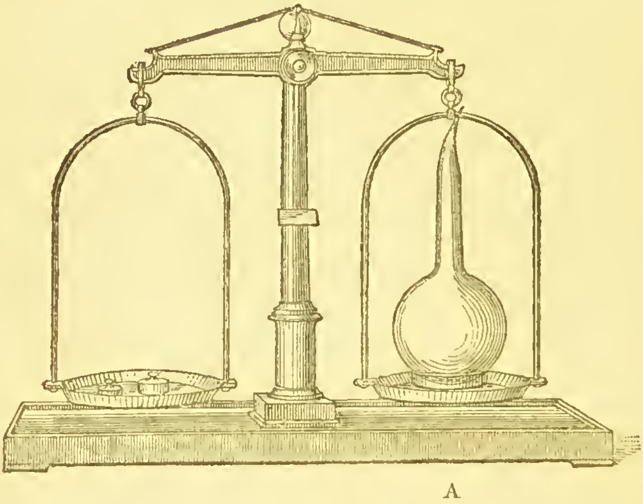


Fig. 1.

If air is a material thing, it must exert a pressure, because of its weight, on every object whereon it impinges. Forestalling what is to be dealt with later, we shall at once convince ourselves of the justness of this conclusion. The following simple experiment will serve our purpose. We take a flask which has been sealed after all the air has been pumped out of it, and bring the neck under water as shown in the figure (fig. 2); we then break off the end of the neck. We see the water at once rush rapidly into the flask and fill it. The reason of this is that the air outside the flask presses on the surface of the water in the vessel *A*, and, inasmuch as there is no contrary pressure inside the flask from which the air has been exhausted, this pressure causes the water to rush inwards through the opened neck of the flask.

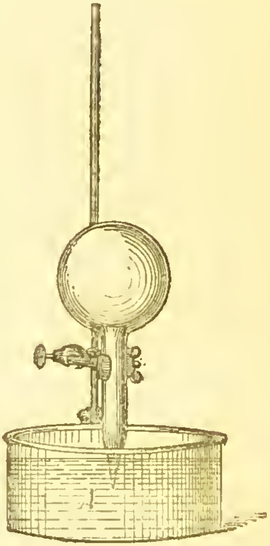


Fig. 2.

Had we conducted a similar experiment, using a very long tube in place of the flask, we should have noticed that the pressure of the air would have held up the water to a height of more than 10 metres. If in place of water we use mercury, a liquid which is about 13·5 times heavier than water, the air will press this upwards to a height about 13·5 times less than that to which it forces water—that is, in round numbers, to a height of 760 millimetres [30 inches]. A column of mercury 30 inches high is in equilibrium with the pressure of the atmosphere, and as the latter increases or decreases the mercury in the tube rises or falls. For this reason we make use of such a column of mercury, under the name of *barometer* (derived from the Greek word *βαρύς* = heavy), as a measure of the weight, or more correctly of the pressure, of the atmosphere.

By this time we know that the air is a material substance. But now comes the question, Is air a homogeneous body, or is it made up of several constituents?

It can, self-evidently, be no easy task to analyse, that is, to test for its constituents, something which we are unable to grasp in our hands or to see with our eyes; and, indeed, the solution of this most ancient problem was gained only about a hundred years ago.

It is possible to demonstrate to you, without assuming any chemical knowledge on your part, that air must contain at least two components—one, namely, which maintains combustion, and another which does not do this.

For this purpose we proceed as follows. By immersing a glass jar in water we cut off a definite volume of air from the rest of the atmosphere. A little piece of phosphorus is placed in a small basin which is floated on the surface of the water inside the jar (see fig. 3). I now remove the jar, ignite the phosphorus, and again place the jar over the little basin. The phosphorus continues to burn brightly for a short time, while it combines with a part of the air in the jar, and then goes out. While this is going on, the external air-pressure forces water into the jar, to take the place of the air which has been removed, and the removal of which has produced a partial vacuum in the jar, and the quantity of water so driven into the jar corresponds with the quantity of air which has combined with the phosphorus (fig. 4).

An examination of the gas left in the jar shows that it differs from the atmosphere around us in that a burning body, even a substance so combustible as phosphorus, goes out when brought into this gas; and in many other respects the gas is found to be very indifferent—that is, it shows scarcely any inclination to combine with other substances, and so to form new

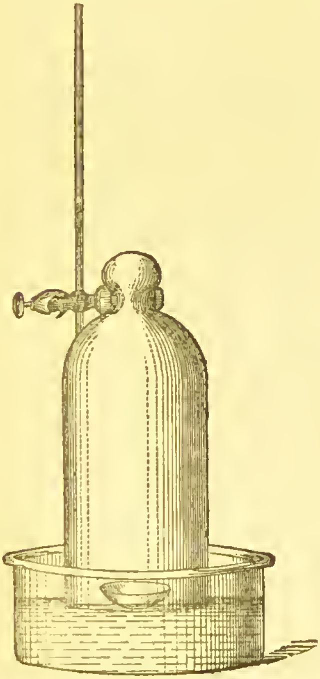


Fig. 3.

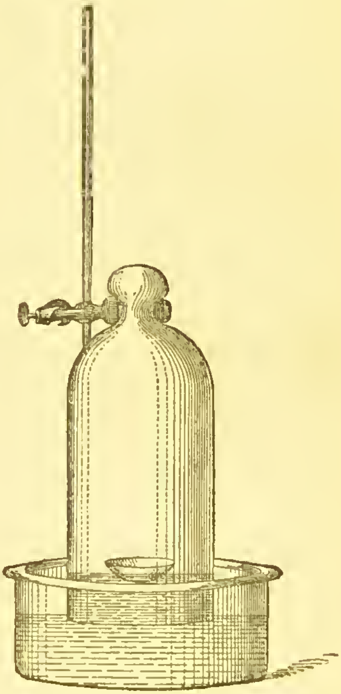


Fig. 4.

bodies. This gas is called *nitrogen*. Living things die in it.

The other part of the air which combined with phosphorus in the experiment just described is called *oxygen*, from the Greek word ὀξύς = sharp or acid. In contradistinction to nitrogen, it is an extremely active body—that is, it is very ready to form new compounds. We have seen a case of combustion (the combustion of phosphorus) attended with flame which was brought about by oxygen, as indeed are all the combustions that occur in practical life.

Oxygen also combines slowly with very many substances without producing flame. The rusting of iron, for instance, that is so dreaded by the housewife, depends on the combination of the metal with the oxygen of the air to form iron oxide, or rust as this substance is commonly called.

We shall become acquainted with a whole series of combinations, like the rusting of iron, of bodies of very different kinds with oxygen; such occurrences can scarcely be called combustions, because we associate the appearance of fire with combustion. These processes are called *oxidations*. The terminal syllable in the often used term *oxide* means, as we now readily understand, nothing but a compound with oxygen. *Lead oxide* signifies a compound of lead and oxygen, and *lead superoxide* a similar compound containing twice as much oxygen, and so on.

When an investigation is made of the air that surrounds us, with an observance of all the rules laid down by science, it is found that air always contains a very little carbonic acid gas and some moisture, besides nitrogen and oxygen; and if a determination is made of the quantity of each of these in 100 parts of air, the following proportions are obtained:

Nitrogen	78·35	parts.	
Oxygen	20·77	,,	
Water in the gaseous state...	0·85	,,	(so-called moisture).
Carbonic acid gas	0·03	,,	
	100·00	parts.	

Chemists call these quantities calculated on 100 parts *percentages*; they say that air contains 78·35 *per cent.* of nitrogen, etc.

It has been found recently that nitrogen separated from air by a chemical method—we learnt to recognise a chemical process a little while ago—is not a homogeneous body, as had been supposed, but that it contains, mixed with it, another gaseous element, to which the English chemists * who discovered it have given the name *argon*.

We are all aware that the ability of the air to take up moisture, and to deposit it again in the form of rain, is of great importance in the economy of nature. In daily life also we make constant use of this capability of the atmosphere to take up water; for on this depends the drying of the wash, or of a floor that has been scrubbed, etc.

We must not forget that modification of oxygen which is called *ozone*, as this substance is often mentioned in ordinary life.

The smallest particles of free oxygen which are present in the atmosphere always consist of two atoms

---

* Lord Rayleigh and Professor Ramsay.—Tr.

(we shall come to the conceptions about atoms in the second lecture). These single atoms of oxygen employ their power of combination in joining together to form pairs, as there is no opportunity for them to unite with other elements in the air. We must ascribe such a power of combination to all atoms; for if we attempt to represent them without this capacity, it is absolutely impossible to understand how compounds of any description should be produced.

Now it happens that, under the influence of electric sparks, and on a large scale during thunderstorms (and there are also other causes of the occurrence), three atoms of oxygen link themselves together; and to the modification of oxygen so produced we give the name ozone. Inasmuch as the third atom of oxygen is held to the others comparatively loosely, ozone combines with other substances more readily than oxygen, and it has a stronger oxidising power than the ordinary oxygen of the air, or, as one is accustomed to say, it is much *more active* than oxygen.

Now that we have got to know the composition of air, the question presents itself why we must have air to live in; for experience tells us that want of air leads to suffocation and cessation of life.

This is explained as follows. The air which we involuntarily breathe in finds its way into the lungs, and there comes into contact with the blood by passing through the walls of the fine capillary veins wherein the blood is circulating. Such thin membranes as the coatings of the veins are quite impermeable by liquids, but allow gases to pass through them freely, or, to use the technical expression, to diffuse through them.

When, then, the blood comes into contact with the oxygen of the air by diffusion, the blood absorbs oxygen, and at the same time gives up carbonic acid gas. We should therefore find the expired breath to be rich in carbonic acid; and it is easy to prove experimentally that this is the case.

For this purpose we will draw some external air through clear, filtered lime-water by sucking with the mouth at *A* (fig. 5). There is so small a proportion of carbonic acid in the air that no visible change is made in the lime-water in the short time during which the experiment lasts; but when I blow expired breath through the same lime-water by means of the small tube *B* (fig. 6), a turbidity, which is visible at some distance, quickly appears in the liquid. This means that the carbonic acid gas in the expired breath has combined with the lime to form chalk, which, being insoluble in water, is diffused through the liquid as a fine powder.

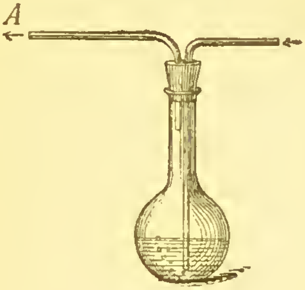


Fig. 5.

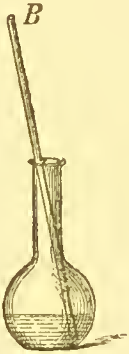


Fig. 6.

The following analysis of a sample of expired breath, which had been deprived of moisture, shows how considerable is the quantity of carbonic acid in the breath sent out from the lungs :

Nitrogen	79·557	per cent.
Oxygen	16·063	,,
Carbonic acid gas	4·380	,,

While the oxygen has been reduced by about one-fifth, the quantity of carbonic acid has been increased about a hundred-and-forty-fold.

The oxygen which has been absorbed by the blood is carried by the blood through the whole of the body, and brings about oxidations. Particularly, it burns to carbonic acid the carbon of many substances—which are naturally always being re-formed by the help of the nourishment taken into the body—and the blood returning to the lungs carries with it this carbonic acid gas, which originates from the tissues, etc., in the most different parts of the body, and there gives it up in exchange for oxygen.

The continuous oxidation which takes place in the body as a consequence of breathing is accompanied, like every other process of burning—for oxidation is merely another name for burning—with the production of heat ; and it is this heat which maintains our bodies at their normal temperature of 37° C. [98° F.].

When we consider that the circulation of blood from and back to the heart occupies only about ten seconds in a man, we easily understand how our bodily temperature is kept constant in all parts of the body by this process, notwithstanding that we are continually parting with a considerable quantity of heat to our colder surroundings. In a subsequent lecture we shall discover what weight of carbon must be burnt daily for this purpose. But even now it is clear from what has been said that the supply of carbon compounds in the body must soon be exhausted unless there be sufficient compensation; and hence, as well as to make up for other withdrawals, we are compelled to absorb sufficient quantities of nourishment.

Before leaving our present subject, we shall glance for a moment at the processes of combustion, and next time we shall deal in more detail with the phenomena of flame which accompany combustions, as both of these are conditioned by oxygen, about which we have learnt something.

All the materials used in ordinary life for burning are rich in carbon; wood and turf, for instance, have been used for ages, and in more recent times coal and peat have come into use, as fuel. The process of burning such fuels consists, in the main, in the combination of the carbon of the fuel with the oxygen of the air to form carbonic acid, while at the same time the small quantities of hydrogen in the materials are burnt to water.

Carbon and oxygen do not combine when cold; but if the combination is started, the material continues to burn, since the heat produced by the part which is burnt directly suffices to make the neighbouring parts hot enough to begin burning—that is, so hot that combination of carbon with oxygen occurs.

We cannot at present go into the methods that have been so fully developed nowadays for the most economic employment of fuel; but when we come to speak of the metallurgy of iron, we shall have occasion to learn something more fully of these methods in connection with the processes for manufacturing that metal.

The question as to how combustible material is set on fire, how the burning is generally started, has still to be answered. Nowadays it is very easy: we use matches; but matches came into use only about sixty years ago. The question must always remain unanswered as to whether primitive man became acquainted with fire by rubbing pieces of dry wood together, or by obtaining it from a tree which had been ignited by a lightning-flash. It is certain that fire can be obtained by rubbing together pieces of wood; and travellers have found this method in use among distant tribes in the present century. The method, however, requires the wood to be drier than we ever find it in its natural state in our climate. The difficulty of getting fire anew, and, therefore, the immense importance of maintaining the fire which had been started, explain the fact that all the older races looked on the hearth, where this supreme possession was maintained continuously, as a sacred place.

The process of obtaining fire by allowing the sparks produced by striking a piece of steel and a flint together to fall on to tinder or dry fungus was discovered in the later Middle Ages.

Since the beginning of this century isolated attempts were made to devise a method for getting fire, which could always be conveniently applied, by employing some one of the processes—and there are many of them—in use in chemical laboratories. The results of these attempts were but small, the methods themselves were very inconvenient and untrustworthy, and the apparatus was sometimes absolutely dangerous, until in the thirties use was made of *phosphorus.*

About that time a young Austrian mechanic, Johann Jrinyi, hit on the notion of using phosphorus, experiments with which substance he had seen made in a lecture. Sulphur-matches, which were little slips of wood tipped with sulphur, were in common use at that time for obtaining fire; Jrinyi added a little phosphorus to the sulphur, and the lucifer-match was made.

Phosphorus, as is generally known, takes fire when rubbed; the burning is passed on by the phosphorus to the sulphur, and from the sulphur to the wood. It was of course not so easy to surmount the technical difficulties and to manufacture really good lucifer-matches. But after a time matches of unexceptionable quality were prepared.

As a fire-producing material the lucifer-match left nothing to be desired; but these matches had other properties which have led to their replacement of late years by what are generally called safety-matches.

Phosphorus is extremely poisonous; the lucifer-match placed the general public in possession of this dangerous substance; and the substance had also deadly effects on the workers in match factories, many of whom suffered from terrible diseases in their bones.

Ordinary phosphorus is yellow; but it possesses the remarkable property of changing into a red powder, known as *red phosphorus*, when it is heated for some time to about 250° C. [482° F.] in a closed space—heated in the air of course it burns—such as a vessel with a tightly fitting cover. This transformation can be shown here easily in the following way. A small quantity of yellow phosphorus is placed in the glass tube A (fig. 7), and the tube is closed by fusing together the glass at the open end; the tube is then suspended in a wider tube, wherein is placed a liquid that boils at 250° C. [482° F.]. The liquid is now caused to boil, and the tube A is thus surrounded by the vapour of the boiling liquid, which soon heats A to 250°, and we see the yellow phosphorus gradually changing to a red mass.

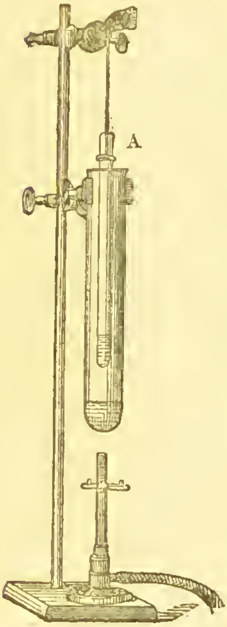


Fig. 7.

Now red phosphorus is not poisonous, and it is also much more difficult to ignite than yellow phosphorus; it is, indeed, so uninflammable that it does not take fire when rubbed on any casual surface. To ignite red phosphorus by rubbing requires that the surface, contact with which causes the ignition, should contain chemical substances very rich in oxygen. The mixture used in preparing the rubbing-surface for safety-matches consists of 32 parts chlorate of potash, 12 parts chromate of potash, 32 parts peroxide of lead, and 34 parts sulphide of lead; the first three of these substances are characterised by the large quantities of oxygen they contain. If we prepare a little of this mixture—the preparation must be done carefully, as the mixture is very explosive—and set fire to it, the mixture detonates with that bluish white light we are accustomed to notice when a safety-match is struck.

LECTURE II.

Nature of flame (1).—Candles.—Composition of fats.—Oils.—Petroleum.—Hydrocarbons.—The elements.—Tetravalency of the atom of carbon.—Chemical formulæ.—The atom and the molecule.—Distillation.—Petroleum ether.—Vaseline.—Paraffin.—Manufacture of coal-gas and bye-products.—Nature of flame (2).—Cooking by gas.—Incandescent gas-lights.

It is well known that the burning of substances which contain carbon serves not only for the production of heat, but also for lighting purposes. But flame is produced only by those carbon-containing materials which are converted into gas or vapour when they are burnt; this will be proved by experiment very shortly.

Compounds which contain very much carbon, such as wood, coal, or tallow, are not, indeed, themselves volatile, but they burn with a flame because they give off combustible gases when they are heated. The flame is therefore nothing else than a burning gas which is constantly being produced from the material.

If we now set fire to a piece of wood, we see that it burns with a flame; but if we have previously removed from the wood everything that will volatilise, by heating the wood very strongly out of contact with the air, we find that the wood charcoal thus produced will not burn with a flame.

It is possible to draw the gas out of a flame—out of a candle-flame for instance—and then to burn the gas. The method of doing this is as follows. We introduce a glass tube into the flame; one end of this tube is drawn to a point, and the other end passes through a cork which is fitted into a cylinder quite filled with water. Another glass tube passes through the cork, and reaches to the bottom of the cylinder; this tube is connected with a piece of caoutchouc tubing, and the glass and caoutchouc tubes are filled with water, and so act as a syphon (see fig. 8). Water is now allowed to flow slowly from the caoutchouc tube by

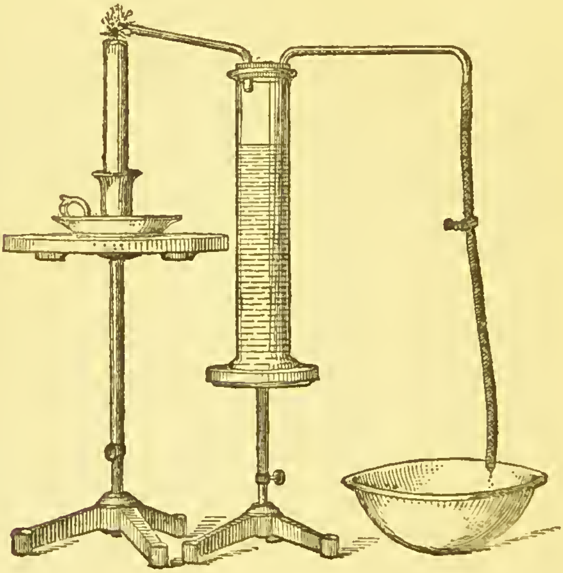


Fig. 8.

partially opening a pinch-cock placed on this tube; suction is thus produced at the point of the glass tube in the candle-flame, and some portion of the gases and vapours is thus drawn from the flame into the cylinder. As the process continues the flame becomes conspicuously smaller because we are removing part of the material which feeds it. It is necessary to suck gently to avoid getting air into the cylinder along with the vapours from the flame. When the cylinder is filled with the gases from the flame, the cork is removed, and a light is brought to the mouth of the cylinder; the contents of the cylinder—that is to say, the gas derived from the candle—take fire and burn quietly. This experiment furnishes a proof of the justness of the statement made at the beginning of this lecture.

Let us now get some fuller knowledge respecting the three chief materials used for lighting purposes. These three substances are candles, oil, and coal-gas. We shall not concern ourselves with electricity as a source of light, as this has nothing to do with chemistry so far as that study interests us at present.

Candles represent the solid form of light-giving materials. In the older days candles were prepared by melting tallow, and also animal fat, in a vessel, and dipping wicks into the melted substance. By repeatedly dipping in the same wick the tallow candle was formed. These candles burnt very imperfectly; the ends of the wicks required to be constantly removed by snuffers, a kind of scissors which has already passed almost out of remembrance. A glance at the tallow candle which was lighted at the beginning of the lecture will show the mode of burning of these candles (compare fig. 9). The reason of the imperfect burning of these candles was as follows. We know that the tallow is volatilised by the high temperature of the flame; this volatilisation of course takes place from the wick, which sucks up the fat that is melted in contact with it where the flame produces heat sufficient to cause the volatilisation; the gases thus produced make their way into the air, and are burnt there by the aerial oxygen, which converts the carbon into carbonic acid and the hydrogen into water. The wick itself does not come into contact with the air, as the ascending gases cut it off therefrom; the wick is therefore carbonised by the heat, because the carbon of the wick cannot burn for lack of oxygen, and after a time the carbonised end of the wick prevents the flame from burning symmetrically. Symmetrical burning begins again when the end of the wick is removed, or, as used to be said, when the candle is snuffed.

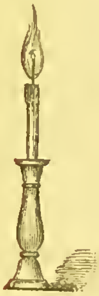


Fig. 9.

All this seems to us to-day rather unimportant, as we no longer suffer personally from the inconvenience of constantly snuffing our lights. Goethe, however, could still say in his maxims in rhyme:

> Wüsste nicht, was sie besseres erfinden könnten,
> Als wenn die Lichter ohne Putzen brennten.

And it must surely have been anything but pleasant to break off one's reading of an evening, perhaps every half-hour, to snuff the candles, whose light had sunk so low that reading was no longer possible.

These tallow candles were made from natural fat. The chemical examination of fat, which began to have successful results about the end of last century, led at last to the stearin candles we use to-day. This investigation showed that all fats which are derived from animals or plants can be resolved into two main constituents—namely, into several fatty acids, and into *glycerin*.

In the fat of animals, in oxen-fat for example, three fatty acids—called *stearic*, *palmitic*, and *oleic acids*—are found in combination with glycerin. The two first named acids are solids, the third is a liquid; and the more *oleate of glycerin* a fat contains the less solid it is. Swine-suet and goose-suet, for instance, are very rich in the last named substance. Fat is easily split up into its two constituents by technically applicable processes, and the mixture of the three fatty acids thus obtained is freed from oleic acid as far as possible by pressure. The white cake which remains is further purified, and from this stearin candles are made. Before melting and running into the form of candles, 10 per cent. of *paraffin*—we shall learn immediately what that is—is added to the cake, and this produces the homogeneous white wax we commonly see in stearin candles. A mixture of stearic and palmitic acids without this addition crystallises easily as it cools, and candles made from such a mixture show a certain streakiness, which is prevented by the addition of paraffin.

The wick, round which the mixture is poured in making the candles, is tightly twisted on its axis, and this twist remains when the material hardens; the result is that when the candle is gradually consumed, after it has been lighted, the wick is always bent, and by this means the end of the wick is constantly and automatically kept out of the flame. Now there is sufficient oxygen outside of the flame to insure the complete combustion of the wick, and in this way an unburnt head never gets formed, snuffing is not needed, and stearin candles burn perfectly symmetrically. This artifice could not be applied to tallow candles, because the material of which they were made was too soft to maintain the necessary twist in the wick.

We must also make mention of wax candles. Bees'-wax, which is an animal fat, is very like other fats in its chemical relations. This wax consists of fatty acids and an alcohol; glycerin is also, chemically, an alcohol. The fatty acids in bees'-wax are *cerotic* and *palmitic acids*; they are combined in the wax with *myricyl alcohol.* As bees'-wax is harder than tallow, candles made from that wax are found to be better than those made from tallow.

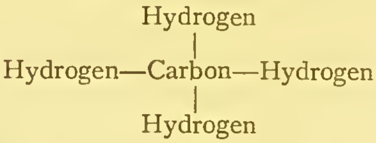
Olive oil and oil of rape-seed were the liquids most commonly used as burning materials thirty years ago; wicks were dipped into the oils, and they were burnt in lamps adapted for the purpose. These oils are closely related chemically to the fats; they consist of fatty acids and glycerin. The fatty acids present in them in greatest quantity are of course liquids.

Petroleum, which is now much more used than the oils we have been speaking of, is quite a different substance; it is a mixture of *hydrocarbons.* As we often find this expression, *mixture of hydrocarbons*, in the newspapers, we must try to understand clearly what it means; for this purpose we shall do well to devote a little time to the consideration of the chemical aspects of the matter.

In chemistry one speaks of the elements. By that term is understood those constituents of bodies which have not been separated into simpler substances in any of the many attempts that have been made to effect such separations. About seventy such elements are known. Most of them are very rare; only about twenty play a part in daily life; and the whole world with which we have ordinarily to do is constructed from these few building stones. Hence we should expect to find, as indeed we do find, that the variety of their combinations is astonishingly great.

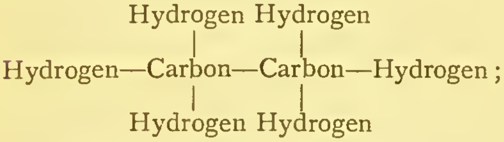
Now carbon is the element which far surpasses all the others in its power of forming combinations; the variety of ways wherein atoms of carbon are able to combine with the atoms of other elements, or with other atoms of carbon, is greater than the ways of combination of all the other elements taken together. And when nature created living things she made use of carbon. Therefore it follows that carbon is present in every substance which is connected with the existence of life; be it the seed of an apple, or the flesh or the bony skeleton of an animal, all are interpenetrated with compounds of carbon.

The quite innumerable number of carbon compounds may be brought into an easily comprehended system by making the compounds with hydrogen the starting-point of the complete scheme. One atom of carbon is able to bind to itself four atoms of hydrogen; or, as is commonly said, the atom of carbon is tetravalent. This may be represented as follows :



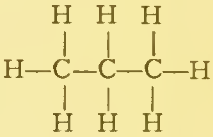
$$\begin{array}{ccccc} & & \text{Hydrogen} & & \\ & & | & & \\ \text{Hydrogen} & — & \text{Carbon} & — & \text{Hydrogen} \\ & & | & & \\ & & \text{Hydrogen} & & \end{array}$$

Now we have already mentioned that carbon atoms are able to form connected chains with one another; and this leads to the formation of new hydrocarbons, in which the carbon atoms are held together besides being in combination with atoms of hydrogen. Thus :



$$\begin{array}{ccccccc} & & \text{Hydrogen} & & \text{Hydrogen} & & \\ & & | & & | & & \\ \text{Hydrogen} & — & \text{Carbon} & — & \text{Carbon} & — & \text{Hydrogen} \\ & & | & & | & & \\ & & \text{Hydrogen} & & \text{Hydrogen} & & \end{array}$$

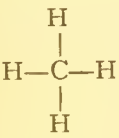
; and



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & — & C & — & C & — & C & — & H \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

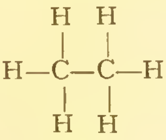
In these instances we have connected together as many as three atoms of carbon ; and we may go further —these chains have been formed with sixty atoms of carbon. Such rows of atoms may ramify in the most different directions; the carbon chains may, indeed, return upon themselves in the form of rings—with which we shall have to deal in the last lecture, where some of the more recently introduced therapeutic agents will be considered. It is very evident, then, that the number of possible hydrocarbons is immense.

In representing the three hydrocarbons referred to above we began by writing the names of the elements in full, and then we shortened these names by using only the initial letters of them without interfering with the intelligibility of the *chemical formulæ* of the compounds ; for the way of writing the third hydrocarbon is indeed an actual chemical formula. The letter *C* stands for carbon, and *H* for hydrogen; and these letters are used as the symbols for those elements in all languages. Employing these symbols, and adopting the same method of representation as before, we have the following formulæ for the three hydrocarbons, which are the formulæ in common use in the chemical text-books:



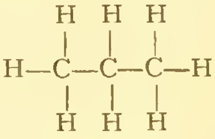
$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

Methane



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

Ethane



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

Propane

American petroleum contains many hydrocarbons with "*single chains of carbon atoms*," belonging to that series the initial members of which we have here formulated, and the technical names of which we have given.

The first member of this series is a gas; it contains much hydrogen, which is the lightest element known. This hydrocarbon is formed in the decay of vegetable matter in presence of much water; it is found, therefore, in the gases arising from marshy places, and for this reason it is called *marsh-gas*.* Chemists give to it also the name *methane*.

The collection of this gas from a marsh is an easier

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* It appears, from a letter of the celebrated Italian naturalist Volta to a French scientific friend, that Volta knew in 1776 that every marsh gave off this gas, or, as we might say to-day, was a kind of gas factory. The term *volt*, applied to-day to the pressure of an electric current, is derived from the name of the Italian naturalist; as the term *ampère*, used in measuring the quantity of the current, recalls the French physicist of that name. These terms are constantly heard since the introduction of

The distillation apparatus represented here is that commonly used in laboratories. The liquid is heated to boiling in a flask, and the vapour which rises from the boiling liquid passes through the side-tube, sealed on to the neck of the flask, into the condensing-tube, which is surrounded by a wider tube through which a stream of cold water is kept constantly passing. The vapour is thus cooled, and in consequence of this it becomes liquid again, and finds its way in drops into the receiver. A thermometer fastened into the neck of the distilling-flask serves to determine the temperature whereat the distillation is proceeding. The apparatus used in manufactories is made of metal, and is of course larger, but the principle is the same.

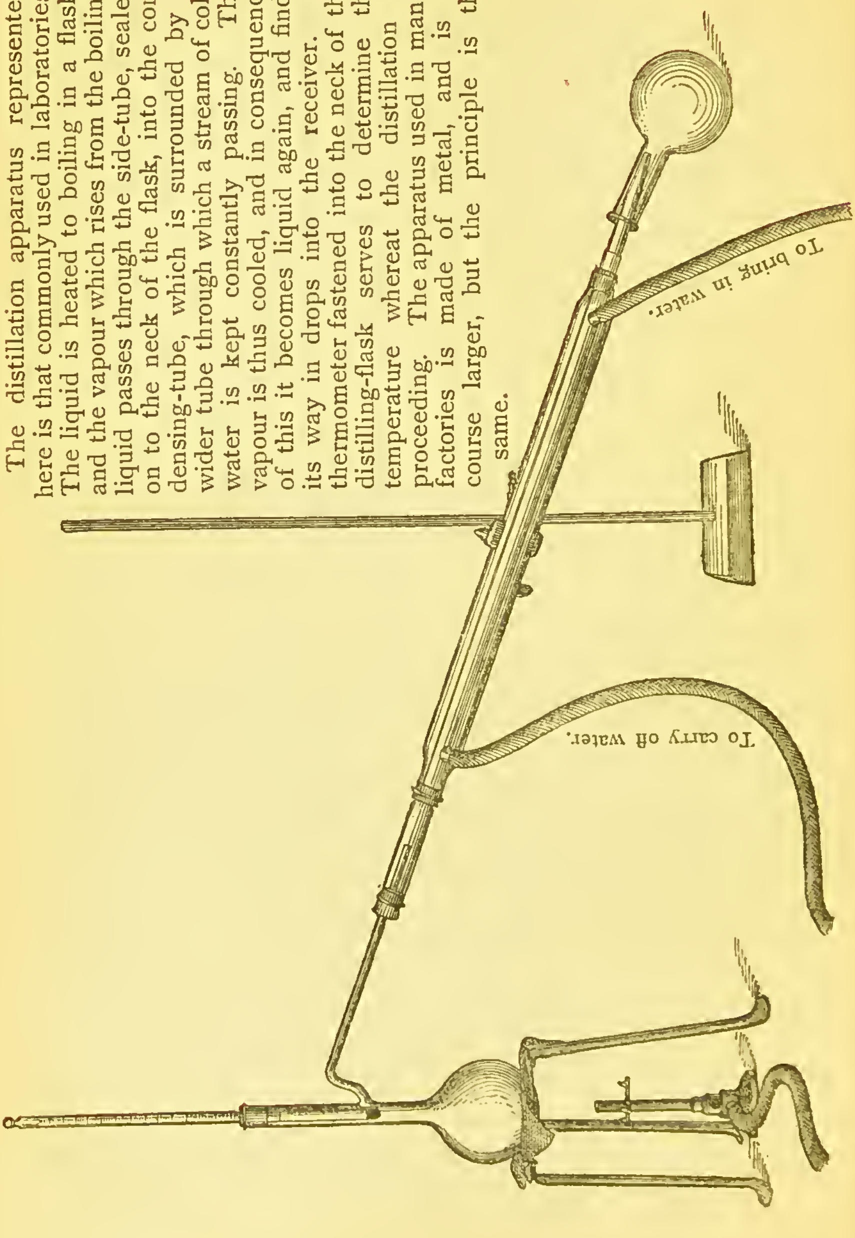

Fig. 10.

matter than one might be ready to suppose. It is only necessary to sink a large funnel in the marsh, with the wider open end downwards; the gas then collects in the funnel, and bubbles upwards, and it may be collected in a suitable apparatus connected with the narrow end of the funnel.

The second hydrocarbon, *ethane*, whose molecule contains six atoms of hydrogen, is a gas; as is also the third, *propane*, which contains eight atoms of hydrogen. This third hydrocarbon is found dissolved in crude petroleum.

Before proceeding further we must give some explanation of the term *molecule*, which has just been employed. The smallest, undecomposable parts of elements are called *atoms*, a term derived from a Greek word signifying indivisible. Now the smallest parts of all bodies which are not elements must consist of atoms of the elements which compose these bodies; such a smallest part of a non-elementary body we call a molecule. For instance, the smallest part of a hydrocarbon which we are able to picture to ourselves is a molecule, inasmuch as it is always formed by the union of atoms of carbon and atoms of hydrogen.

When we come to that hydrocarbon which contains four atoms of carbon, we find that it is a liquid; a liquid, it is true, which boils at 1° C. [33·8° F.]. In keeping with this, it is found that the greater the number of carbon atoms in the molecule of a hydrocarbon the

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electric lighting. Accurate analyses of marsh-gas, on which we base the statement that it consists of four atoms of hydrogen combined with a single atom of carbon, were carried out about forty years after the discovery of the gas.

higher is the boiling-point of the compound; for instance, *hexane*, a hydrocarbon with six carbon atoms found in petroleum, boils at 70° C. [158° F.]. As the quantity of carbon increases the compounds become less fluid, and at last even solid.

Large quantities of hydrocarbons are present in crude petroleum. When this is distilled, that is, is heated so that whatever is volatilised at the higher temperature is again cooled by means of a condensing arrangement and is then again liquefied—somewhat in the manner shown in the figure on p. 26 (fig. 10)—the gaseous compounds are first given off; then come the lower boiling portions which are known commercially as petroleum ether.

Petroleum ether often gives rise to explosions; the reason of this is as follows. The volatility of this substance is so great that it very easily evaporates into the air—say, into the air of a room; if now this mixture of air and hydrocarbon vapour comes into contact with a flame, the hydrocarbon is burnt, very suddenly, by the large quantity of oxygen present, to carbonic acid and water; and this sudden combustion is accompanied by an explosion. This substance is often used to remove grease stains, etc.; it should be handled only in daylight, and as far as possible near an open window. As the distillation of crude petroleum proceeds the boiling-point gradually increases; this is made apparent by looking at the thermometer fixed in the neck of the flask. At a certain temperature the receiver is changed, and the distillate is collected apart from what has come over before; this distillate is our ordinary petroleum.

The laws of almost every country demand that commercial petroleum shall fulfil certain requirements as regards its inflammability, and these requirements are such that the risk of explosion by the burning of petroleum in our ordinary lamps is almost completely removed. Before these regulations were put into practice it often happened that petroleum contained some of what we now call petroleum ether, and that this volatilised in the reservoirs of the lamps. As soon as the mixture of this vapour and the air in the reservoir became of the proper composition, it ignited at the flame of the lamp, an explosion took place, and the lamp was shattered.

Those portions of crude petroleum which distil over after the ordinary petroleum is removed have the consistence of butter; they are worked up into vaseline. Other portions, especially portions of Caucasian petroleum [and of the oil obtained by distilling shale], are used as lubricating oils for machinery.

The substance already referred to under the name of paraffin is a mixture of hydrocarbons which contain much carbon in their molecules, and are therefore solids at the ordinary temperature. These do not come from petroleum, but from tar, a substance obtained by the dry distillation of coal or shale—we shall consider this process immediately. The industries based on the distillation of coal and shale are conducted on a large scale in Mid Germany, [and also in Scotland].

It can readily be understood that candles may be made of paraffin only. But such candles do not meet with much approval, inasmuch as their transparent whiteness is not so pleasant to the eye as the opaque white appearance of stearin candles, and also because, if they are as long as stearin candles, they generally become bent, as they burn, from their own weight.

In speaking of materials used for giving light, we now come to the consideration of coal-gas.

When such a substance as wood, peat, or coal is placed in a closed iron tube like that represented by *A* in the figure (fig. 11), and the tube is heated very highly,* whatever in the material is volatile at the temperature employed will be driven out and will pass through the exit tube into the vessel *B*. In this process the substance heated is said to be submitted to dry distillation. Those portions of the substances volatilised from the wood or coal which are liquids at the ordinary temperature will collect, in the form of tar and what is called ammonia water, in *B*, while that which is gaseous at the ordinary temperature will pass through *C*, and will be collected in the glass jar *D*, which here serves as a gasometer. The glass jar *D* may well be called a gasometer, inasmuch as our apparatus represents, on a small scale, the main parts of a gas manufactory. In an actual gas works only gas-coal is used as the material; and in place of large iron tubes retorts of fire-clay are employed, because these better withstand the continued action of the heating furnaces. One hundred kilograms of good gas-coal yield from 28,000 to 30,000 litres of gas weighing about 18 kilograms, and about 5 litres of tar and ammonia water, while about 70 to 75 kilos. of

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* For this purpose we use a long gas furnace.

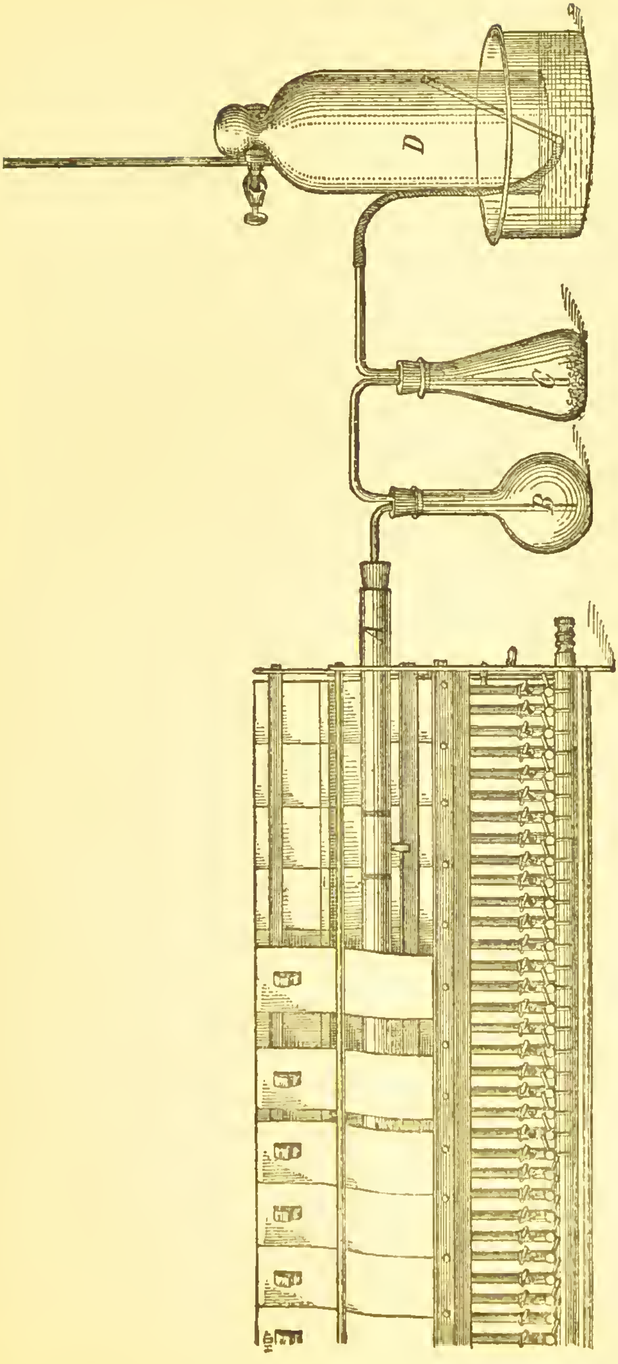

Fig. 11.

coke remain in the retorts. [One ton of good gas-coal yields about 10,000 to 11,000 cubic feet of illuminating gas, about 10 to 13 gallons of gas-liquor, and from 1,000 to 1,500 lbs. of coke.]

On the large scale the tar is got rid of by cooling—the flask *B* fulfils this purpose in our small-scale experiment; after this the gas is brought into contact with water—it is washed, as the expression goes. Those constituents of the gas which are soluble in water are thus removed. The most important of these, so far as quantity goes, is ammonia; were this allowed to remain in the gas the quality of the gas would be deteriorated.

Ammonia gas is composed of nitrogen and hydrogen; these elements are present in gas-coal in the form of very complex compounds, which are decomposed at the high temperature to which the retorts are subjected with production of the simpler compound ammonia. Ammonia gas is very soluble in water; in this dissolved form it is known to every one as the very sharply-smelling "*spirits of hartshorn.*" We shall see later what uses are made of the large quantities of ammonia that are obtained from the gas factories of the world.

In the apparatus which we used (represented in fig. 11) a flask, *C*, was placed between *B* and the gasometer. This flask represents the vessels employed on the large scale for purifying the gas; these are filled with the purifying material, which is for the most part a mixture of slaked lime and oxide of iron. The slaked lime serves to remove carbonic acid from the gas by combining with it to form chalk; the presence of carbonic acid cannot be prevented entirely in the process of manufacture. We learnt in the first lecture to use the formation of chalk as a means for detecting carbonic acid in expired breath. Inasmuch as carbonic acid is the final product of the burning of carbon, this compound cannot itself be burnt; if, therefore, it is left in coal-gas, the gas is thereby diluted and deteriorated. The oxide of iron in the purifiers is for the purpose of withdrawing gaseous compounds of sulphur from the coal-gas; it does this by combining with the sulphur of these compounds to form sulphide of iron. If any sulphur is left in gas, this sulphur burns, when the gas is lighted, to sulphurous acid, which is a gaseous body with a pungent smell, well known to every one as the smell of burning sulphur; some of the sulphur is also burnt to sulphuric acid at the high temperature of the flame of coal-gas.

These purifiers remove almost all the sulphur from the gas, except that which exists in the form of a compound called bisulphide of carbon. The quantity of this compound in coal-gas is extremely small; but its complete removal on the large scale remains to-day an unsolved problem of the gas trade.

When the gas has been purified in the way described it is collected in gasometers, and it is conducted from these in pipes to the places where it is to be used.

The following analyses will give an idea of the composition of coal-gas:

Hydrogen	45·2	per cent.	by volume.
Methane (see p. 25)	35·0	,,	,,
Other hydrocarbons	4·4	,,	,,
Carbon monoxide	8·6	,,	,,
Carbonic acid	2·0	,,	,,
Nitrogen	4·8	,,	,,
	1000		

When coal-gas is burnt, carbonic acid is produced from the carbon, and water from the hydrogen, of the gas ; on account of the high temperature the water is produced in the gaseous form. Thus coal-gas is almost wholly changed, by burning, into two odourless, colourless gases. Besides these gases, the air of rooms wherein coal-gas is burnt contains a little sulphurous acid gas, produced by the burning of the traces of sulphur-containing compounds in the gas. It is on account of this sulphurous acid gas that window plants do not flourish well in rooms wherein coal-gas is burnt. The small quantities of sulphurous acid produced by burning coal-gas are found, fortunately, to be quite harmless to human beings.

It has been said above that part of the sulphur in gas is burnt to sulphuric acid. This result of the combustion is made apparent in the spots that appear on the globes of gas-lamps when these globes are not very frequently cleaned. Small drops of liquid sulphuric acid settle on the globes, and, as sulphuric acid is an extremely corrosive, that is destructive, substance, the particles of dust that fall upon the globes are charred by it. Hence it is that the globes of such lamps get gradually covered with brownish specks ; such specks are not seen on the chimneys used on lamps for burning oil or petroleum, inasmuch as these substances do not contain sulphur.

What remains to be said about the nature of luminous flame can now be made clear and illustrated very conveniently in connection with the flame of coal-gas.

The presence of carbon in the luminous flame is demonstrated by holding a porcelain plate in the flame, when, on account of the cooling effect of the cold surface, carbon is deposited on the plate in the form of soot. This carbon was separated in the flame itself by the heat of the flame; and as at the same time it was raised to a white heat it caused the luminosity of the flame. When this carbon reaches the edge of the flame and there comes into contact with the oxygen of the air, it is burnt to carbonic acid, and in this form it escapes into the surrounding atmosphere. It can easily be shown that this is actually what occurs. Those of you who cook by gas—a method which is rightly coming more and more into use in the kitchen—always use non-luminous gas-flames, which do not cover the cooking-vessels with soot because no separation of carbon occurs in such flames. Chemists have employed gas, when it was to be obtained, for heating purposes for the last fifty years; they make use of the burner invented by Bunsen, which burner has of late years been adapted to apparatus for cooking by gas. In a Bunsen burner the gas issues from a narrow opening. If it is lighted at this opening the gas burns with the ordinary luminous flame; but if there is placed over this opening a tube with holes for admitting air near to the opening from which the gas issues (see fig. 12), the gas streaming through this tube is able to carry a little air with it. If we now light the gas at the open end of the tube the flame is non-luminous, because there is so much air mixed with the gas that the oxygen in this air suffices to cause combustion of all the carbon

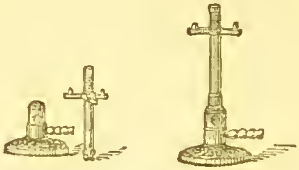

Fig. 12.

in the gas; at the same time a great heating effect is produced. If the holes in the tubes are closed the flame burns luminously, as we should expect.

The arrangement in all gas-cooking apparatus is exactly similar to that used in the Bunsen burner. You see that the gas issues from a small opening immediately in front of the stop-cock, and near this you see several openings for the entrance of air into the wider tube which conducts the mixture of gas and a little air to the place where it is to be burnt. Should too much air get into the tube by accident we should have, of course, an explosive mixture; were this ignited the gas would burn for a moment, and the flame would then strike back to the opening by which the coal-gas enters the tube, where it would burn, as at this point it would come into contact with the external air, which would still be needed to maintain the combustion.

As has been already indicated, a non-luminous gas-flame gives out very much heat, because of the rapid combustion that is proceeding in it. If we hold a bundle of platinum wires in such a flame, the platinum, which is not itself in the least changed at this temperature, becomes heated to full redness and radiates light. The latest important advance made in lighting by gas—namely, the incandescent gas-light—exhibits this process in a very complete way. In the incandescent gas-light the flame is rendered non-luminous by the admission of air, in the same way as in the Bunsen burner. We may always notice several small openings—generally four—in these incandescent lamps, placed near the point where the gas enters the burner. The very hot, non-luminous flame heats a hollow mantle suspended in it to a very high temperature. This mantle is saturated with certain oxides, partly the oxides of rare elements such as oxides of cerium and thorium, which have long been known to emit very clear light when they are heated.

Auer was the first to turn this property successfully to account in daily life. He busied himself with the matter for a long time. So long ago as 1885 he had constructed an incandescent lamp for lighting rooms; but the lamp was made serviceable only in October 1891, and since that time it has been much improved by him, especially by so mixing the most appropriate oxides in the mantle as to produce a white light pleasant to the eyes, in place of the somewhat faded, moonshiny colour which the light possessed when it was first introduced.

LECTURE III.

Food of plants.—Manuring.—Fallow land.—Artificial manures.—Bones.—Superphosphates.—Potash salts.—Manuring with nitrogen.—Bases, acids, and salts.—Mother-liquor.—Food of men and animals.—Experiments on digestion.—Albuminoids.—Fats.—Carbohydrates.—Milk and its coagulation.—Cheese.—Soxleht's extraction apparatus.—Fibrin.—Serum.—Artificial fodder.—Gelatin.

We come now to food-stuffs.

The surface of the earth whereon plants and animals live consists of lifeless materials. Plants are able to take all that they require for their life from this lifeless matter which forms the surface of the earth. A tree, for instance, stands in the same place for hundreds of years, and nature supplies it with all that is needed for its existence; rain brings the moisture the tree requires, and the carbon which it needs for forming wood and all that complex structure which renders its life possible it takes from the carbonic acid of the air, etc. The leaves of plants, and, in all probability, more especially the green parts of the leaves, which are called chlorophyll-grains, have the power of decomposing carbonic acid, which itself consists of carbon and oxygen, in such a way that the leaves make use of the carbon and give out the oxygen. This is the more remarkable as carbonic acid is a very stable gas, which can be separated into its constituents in the laboratory only with difficulty, and is itself produced, as we know, at the high temperature of burning flames.

The soil whereon the plant grows furnishes the other inorganic compounds—that is to say, the compounds derived from lifeless matter—that are required by the plant. We get to see these compounds by burning the plant—wood, for instance—when they remain as ashes.

If we examine such plant-ashes more narrowly analyses of them give us the following results. The quantity of ash of a rye-plant, for instance, when the plant is in bloom, amounts to 6·38 per cent. of the weight of the plant; the ash of ripe rye-grains amounts to 1·93 per cent. The ash itself has the following percentage composition—we shall here employ the most simple designations we can:

	Composition of the Ash of Rye-plants. Per cent.	Composition of the Ash of Rye-grains. Per cent.
Potash salts	37·16	34·50
Common salt	0·76	0·90
Oxide of iron	0·50	0·20
Lime and magnesia	12·32	14·13
Phosphoric acid	20·35	47·52
Sulphuric acid	4·03	—
Silica	24·88	2·75
	100·00	100·00

All these things must be contained in the soil if rye, for instance, is to thrive thereon. There is never any lack of some of these constituents, such as silica, which is the chemical name for pure sand, and oxide of iron.

On the other hand, investigations, the consequences of which were fully elucidated for the first time by Liebig, have taught us to recognise that unless the soil is to become exhausted we must add to it *phosphoric acid*, *potash salts*, and *nitrogen*.

We have not as yet become acquainted with the last of these substances in this connection, but we shall get to know something about it. When we consider that all the civilised peoples of whom we know anything have practised agriculture from the earliest times, and further, when we think that Liebig was the first, in the forties of this century, to make clear what part the soil has to play, we must certainly be astonished that such an immense time was needed for mankind to come to this knowledge, and we must the more admire Liebig when we consider that at no time of his life was he a farmer. Even Thaer, who was the great reformer of agriculture, and who was the first to endeavour in a serious way to place this industry on a scientific foundation, and who indeed obtained very remarkable results about the beginning of this century—even Thaer regarded the ash-contents of the plant as only casual constituents. According to him plants flourish the better the deeper is the layer of humus in the soil; he arrived at quite a false conception of the state of affairs regarding the nourishment of plants. It may be said without exaggeration that until Liebig discovered the essential facts all agriculture had been merely a robbing of the soil, whereby in the course of time many parts of the earth had been utterly exhausted.

The observation was made at a very early period that if the same crop is taken from the same plot of ground for several years in succession the yield gradually diminishes; and for this reason the cultivation of crops has always been alternated in a certain cycle.

Thus we find that the books on agriculture which have come down to us from the ancient classical times recommend a rotation of crops; and the works on agriculture which were written before the time of Frederick the Great contain essentially nothing that is not to be found in these ancient writings. We can scarcely speak of progress in agriculture during these ages.

The reason of the increased productiveness insured by practising a rotation of crops lies in this, that, because the composition of the ashes of the various plants is not the same, so the using up of the soil does not take place in the same direction in every year. On the other hand, fields have been manured since ancient times with the waste products at the disposal of the farmer, so that, without exactly knowing why, what had been taken from the soil was returned to it, and the productiveness of the soil was thereby found to be improved. But as much of the produce of the farm is sold a certain quantity of the inorganic salts will be removed annually from the soil without being returned thereto, and for this reason a diminution in the fertility of the soil must take place, notwithstanding the manuring to which the soil is subjected. Ordinary experience proved this to be the case, but no one was able to find the true explanation.

This leads us to the so-called fallow system of farming.

When fields had borne crops for some years they were allowed to remain for a year uncultivated, and this had a real effect in increasing their fertility afterwards. Why this should be so cannot be understood without further explanation. For, if one may put it in this way, neither phosphoric acid nor potash salts are rained from the heavens, and none of these salts comes into the soil from the outside by letting that soil lie fallow; no improvement of the soil takes place in this way.

The good results of the system of fallow depend on the following considerations. The greater part of the phosphoric acid and the potash salts in the soil is present as compounds insoluble in water. Such insoluble substances cannot be made use of by the roots of the plants, as these are only able to absorb substances in solution. Now the moisture in the soil, together with the carbonic acid circulating therein, which is derived from the air, seize on these insoluble compounds and change them into soluble substances. If, then, the store of material that has thus been made available for the nourishment of plants is not withdrawn from the soil for a year, this store suffices, along with that which is dissolved every year, to make it possible after a time to reap a profitable harvest.

It was discovered in the middle of last century that the fields might be sown with clover in the year in which they had until then been allowed to lie fallow without any noticeable diminution in the yield when corn was afterwards raised. What was for that period a great advance was thus made, as more cattle could now be reared, and so more manure could be obtained for the ground; and when the soil became unsuited for growing clover, as experience soon showed did occur, it was possible to raise peas, beans, potatoes, and the like. In this way arose a regular rotation of straw and green crops, with a periodical interpolation of clover.

If the system of fallow was not required, this was only because the different crops, as has already been pointed out, use up very different quantities of the particular inorganic food-salts, so that, by a judicious system of rotation, only small quantities of those salts which are much used were removed throughout the year by cropping the soil. But, without being aware of it, agriculture committed a greater robbery of the inorganic salts of the soil than before; for in order that one field might be more richly manured the neighbouring field was made poorer. The effects of this injury to the soil would have become apparent in our time had not the connection between the soil and the crops been made clear by Liebig, and had not a cheaper substitute for the inorganic salts removed from the soil been obtained from the store that exists in lifeless materials. By these means the system of fallow was made practically superfluous.

The loss which the soil suffers by the removal of the harvest is made good to-day, in so far as this loss is not covered by the natural manure, by the addition of artificial manure. Indeed, as any quantity of artificial manure is at our disposal, the productiveness of the soil can be very much increased by using as much of this manure as experience has shown to be expedient. Hence it is that we have recourse nowadays to the chemical manufactory for the preparation of artificial manures.*

The following are the chief sources whence phosphoric acid can be obtained cheaply—if the cost of the phosphoric acid were great it would be useless to the farmer.

First of all, from bones. These consist for the most part of phosphate of lime; besides this they contain fat and gelatinous substances. The fat is extracted from bones nowadays with petroleum ether, and is used for making candles and soap. We have already spoken of candles, and we shall have something to say of soap later. The process for the extraction of gelatin from bones will not be described, as the understanding of it requires a large amount of preliminary explanation.

When bones are calcined in a closed vessel with an exit tube for the escape of vapour, similar to that wherein coal is heated in the manufacture of gas, a black mass is left behind corresponding with the coke left in the gas-retorts; this black residue is known as bone charcoal [or animal charcoal]. This animal charcoal possesses the property of removing the colour from coloured solutions; for instance, if red wine is shaken with animal charcoal and then filtered, a clear, colourless liquid, like water, is obtained. This property of animal charcoal is made use of in many industries; for instance, sugar-syrup is decolourised by this method. Blacking for shoes is made by mixing very finely ground animal charcoal with some suitable kind of grease.

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* Properly prepared mixtures, soluble in water, of the food-stuffs most valuable to plants, especially those required by garden- and pot-plants, are now to be had in the market and have come into ordinary use. In using these mixtures for manuring plants in pots great care must be taken to add the proper quantity, as the effect of too much of such mixtures is very injurious. About half a gram of such a mixture of food-salts should be used for each kilo. of earth in the pot, and this half-gram should be dissolved in half a litre of water. [About 7 grains per 2 lbs. of earth, dissolved in a pint of water.] If more concentrated solutions than this are used the roots of the plants are likely to be corroded, or even killed. The quantity named above should serve for a year; and half of it should be applied each six months. The quantity of food-salts to be used in a garden depends on the depth to which the soil is trenched. If, for instance, a square metre is dug 20 centimetres deep, then (using the proportion 1 : 2,000) a solution of 100 grams of the soluble food-salts should be employed. [Eleven square feet dug 8 in. deep require a solution of 3½ oz. of the food-salts.]

If bones are calcined in the air the whole of their carbon is burnt away, and a white substance remains. Calcined bones form the material from which phosphorus (which we heard about in the lecture on matches) is manufactured; they are also used in the preparation of *milk glass* (see Lecture X.).

Another source of phosphoric acid is the phosphate of lime which is found very widely distributed over the surface of the earth. This substance, which is known as *phosphorite*, contains varying quantities of impurities. Large quantities of phosphorite are found in Florida, in North America, containing on the average about 82 per cent. of phosphate of lime; and as the impurities in the Florida phosphorite do not materially affect its chemical treatment this American phosphorite finds a market everywhere.

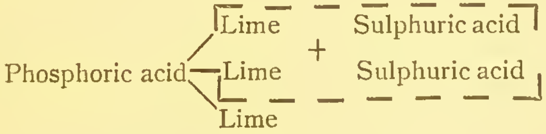
Guano was once of much importance; but in consequence of the exhaustion of the deposits of this substance it is gradually becoming less appreciated. Guano, which is the decomposed excrements of sea-birds, was found in large deposits on the Peruvian coast and the islands off that coast; it is extremely rich in phosphoric acid and contains also much nitrogen.

Finally, the dephosphorising of iron—a process which will be dealt with in the eleventh lecture—produces a substance known as Thomas's phosphate powder, a name derived from the discoverer of the method.

The phosphoric acid in these substances, with the exception of that in the material last mentioned and part of that in guano, is contained in the form of insoluble phosphate of lime, which is also the phosphate present in the soil.

When this insoluble phosphate is brought on to tilled land in fine powder its efficiency is very small, as it is very slowly broken up by the naturally occurring processes whereof we have spoken already. It is, indeed, almost valueless to the farmer, and the plants bring it into an available form only after the lapse of years. But matters are very different if this phosphate is artificially broken up into a form which can be easily and readily assimilated by the roots of the plants. This process of breaking up consists essentially in powdering the phosphate finely, and then treating it with concentrated sulphuric acid.

Most of the phosphoric acid in the materials we have mentioned is combined with lime, in the proportion of three molecules of lime to one molecule of the acid. Sulphuric acid is a stronger acid than phosphoric; but one molecule of sulphuric acid combines with only one molecule of lime. If, then, two molecules of sulphuric acid are caused to react with burnt bones, or mineral phosphorite, a new compound is obtained in which one molecule of phosphoric acid is combined with one molecule of lime, and at the same time two molecules of sulphate of lime, or *gypsum*, as it is commonly called, are formed. The following scheme makes the process more evident:



The phosphate of lime produced in this way is soluble in water, and it is easily assimilated by plants when it is brought into the soil. When one speaks of manuring with phosphoric acid one refers to this compound of phosphoric acid and lime. An aqueous solution of phosphoric acid itself is so corrosive that it would destroy all plant growth.

No objection can be taken to the sulphate of lime which is formed along with, and remains mixed with, the soluble phosphate of lime; indeed, the additional lime salt which is thus given to the soil is in many cases distinctly advantageous.

A word must still be said regarding the *Thomas's phosphate powder*. This substance contains a phosphate of lime which can be assimilated by plants without any preliminary treatment with sulphuric acid. As no money need be spent in artificially decomposing this substance the Thomas's phosphate is a very cheap source of phosphoric acid; it is much used for manuring meadow-land, for which purpose it is particularly suitable.

We come now to the consideration of potash salts as manuring material. Potash salts were very expensive until about the year 1860. Potashes, known in chemical language as carbonate of potash, was the only form in which potash came into the market. As the name indicates, potashes was originally prepared by boiling plant-ashes with water in pots. It was much used in manufactures (glass making, soap making, dyeing, etc.); as the price was very high, and indeed continues high although it is now made from other salts of potash, it could never come into use as a material for manuring. In a later part of these lectures we shall consider this substance in more detail in connection with soda. All the other inexpensive potash salts in use to-day are obtained from the salt-mines in the neighbourhood of Stassfurt, near Magdeburg.

There were many salt-springs in Stassfurt that became exhausted during the last centuries. The exhaustion of these springs led to attempts to get rock-salt by boring in that neighbourhood. The boring brought up a kind of salt which tasted bitter; large quantities of this were thrown aside under the name of *Abraum salz* (useless salt), when pure rock-salt began to be obtained by mining.

These bitter salts are nothing else but salts of potash; and the immense deposits of such salts have caused a great industry to spring up in that neighbourhood whereby agriculturists all over the world are supplied with potash. It is necessary to work up the natural raw salts in manufactories in order to produce a material suitable for use as a manure.

Some of the bye-products of this manufacture are also of technical importance.

It is supposed that these salt layers are the remains of a dried up arm of a sea, which, after the first evaporation, repeatedly flowed over the deposits that had been formed, and in this way produced the great masses of salts that are found in the district.

Bromine is one of the things found in sea-water; this element was indeed first obtained from sea-water in Southern France. Bromine plays an important part in photography, as we shall see later. Now the Stassfurt salts contain bromine, and the preparation of large quantities of this substance from these salts forms one of the minor industries carried on at Stassfurt.

We must now return to the consideration of the nitrogen that is required by plants. Plants require nitrogen for the building up of what is called vegetable albumen—we shall have to speak of this substance immediately when dealing with true albumen—a substance which conditions the life-functions of plants in a similar way to that wherein animal albumen acts. And so it is that want of nitrogen is synonymous with arrest of growth.

We did not find any nitrogen in the ashes of plants (see the analyses of plant-ash on p. 39), because compounds of nitrogen are not fixed in the fire, but are volatilised either unchanged or in combination with other elements; we considered the volatilisation of nitrogen as ammonia, for instance, in dealing with the manufacture of coal-gas.

One would suppose at first sight that plants could never lack nitrogen; we know that the leaves of plants easily take the carbon the plants require from the air, and we also know that 10,000 parts of air contain only 3 parts of carbonic acid, whereas in the same quantity of air about 8,000 parts of nitrogen are present (see p. 9). But, as has been often said, nitrogen is a very indifferent gas, and plants do not possess any arrangement for directly assimilating this inert material.

It is true that the air contains ammonia, which is a nitrogen compound soluble in water; but this substance is present in the air only in traces which must be reckoned in parts per million. Now, as plants are not able to assimilate nitrogen compounds by their leaves, but only by their roots, it follows that, at most, only that part of this ammonia which circulates with the air in the soil, or that which percolates into the soil with the rain, can be available for the plants; and this quantity is quite insufficient to supply the nitrogen required by the plants.

The latest investigations have shown that certain bacilli play a very striking part in the processes whereby plants assimilate nitrogen. There are certain bacilli in tilled soil which, while performing their vital processes, exhibit the remarkable property of causing the combination of nitrogen with oxygen. The compounds that are produced in this way react, in turn, with substances in the soil to form compounds that dissolve in water—chiefly salts of nitric acid—and these soluble compounds are then assimilated by plants. Nitric acid is a product of the oxidation of nitrogen; it is an oxygen compound of that element.

Plants are known, indeed, on whose root-nodules so much nitrogen-containing material is stored, in consequence of the activity of bacilli, that the soil is constantly rendered richer in nitrogen compounds by their growth; such plants are known as nitrogen-gatherers. If, then, plants whose roots do not possess this property are cultivated on a certain soil which has been sown the previous year with these nitrogen-gatherers, those plants find a store of material which supports their growth, although the soil has not been directly manured with nitrogen compounds.

Now, before all this was known, experiments had shown that the addition to the soil of materials that contain nitrogen—or, as one may say, the assistance of the activity of the bacilli—was very beneficial to the growth of plants. Those nitrogen compounds which are soluble in water are of course the most efficient. There are two compounds which can be obtained in such quantities, and at so moderate a price, as to make them suitable to the agriculturist for this purpose.

One of these compounds is ammonia from the gas works. In its chemical relations ammonia is an alkali or a base, for these names have to-day the same meaning. The characteristic property of a base is that it is able to combine with acids; the product of such combination is called a salt. As there is an enormous number of acids and bases, so there is a very great number of salts related to these acids and bases.

Bases and acids may be gases, liquids, or solids. Ammonia, for instance, is a basic gas, carbonic acid is an acid gas, sulphuric acid is a liquid, and silicic acid is a solid. Silicic acid is regarded as an acid because it combines with bases to form silicates; for instance, with potash it forms silicate of potash (see also Lecture X.).

Ammonia is used in agriculture in the form of sulphate of ammonia, which is formed by combining ammonia with sulphuric acid.

Nitre, or saltpetre, is the second source of nitrogen. This substance is produced by combining nitric acid with potash or soda; hence one speaks of potash saltpetre and soda saltpetre.*

Saltpetre has been known for long, and has been used in the manufacture of gunpowder. We shall have to consider gunpowder and the more recently introduced explosives when we have finished what we have to say about food-stuffs. Saltpetre is, however, too expensive for the farmer. The cheaper soda saltpetre is a discovery of our time. This salt is generally called Chili saltpetre, from the name of the country whence it comes. There are great stretches of land in Chili where rain never falls, and where therefore the soda saltpetre that is formed accumulates in the soil. The manufacture of soda saltpetre began about 1830; the process consists in lixiviating with water the soil that contains the salt, filtering, concentrating by evaporation, and then allowing the salt to crystallise out. The liquid which is drained off from the crystals is called the *mother-liquor*; this name is applied, in a general way, to any liquid from which crystals have separated.

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* Salts are called, ordinarily, by such names as *sulphate of potash*, *carbonate of soda*, etc., in accordance with older views of their constitution. Chemists now regard them somewhat differently, and speak of *potassium sulphate*, *sodium carbonate*, etc. The older names are retained in this book, as it is quite out of the question to go into the reasons for the change

When such mother-liquors are evaporated, the salts which were contained therein, in solution, separate out; salts obtained in this way are called mother-liquor salts. The mother-liquor from Chili saltpetre is not evaporated completely to dryness, because it is possible by partially evaporating this liquor to obtain the small quantities of the compounds of iodine which it contains. This comparatively rare element, iodine, is at present obtained chiefly from Chili.

Now that we have become acquainted with the methods whereby plants are able to obtain everything they require for their growth from the inorganic world, including therein the air which surrounds us, let us pass on to consider the food of men and animals.

Man is able to build up his body only from those organic substances which have already been put together by plants. For this purpose he makes use of fruit, grain, etc.; but he can also use animals—oysters, for instance—or parts of animals, such as their flesh. Animals themselves feed on plants, or on other animals, so that the nourishment of the whole animal kingdom is derived primarily from the vegetable kingdom.

Everything which serves us as a food finds its way eventually into the stomach. Those constituents of food which are to be used for building up the body go into solution in the stomach and the intestines, and in this form they can be taken up by the blood, which carries to each part of the body what that part requires.

Let us carry out processes of digestion in several glass vessels by the aid of gastric juice. The coats of the stomach secrete a substance called *pepsin*, and the stomach, in its normal state, also contains a small quantity averaging about two tenths of a per cent. of hydrochloric acid. These two together are able to make soluble the undissolved albumens of the food; or, as is generally said, to transform these albumens into *peptones*.

The pepsin secreted by the coats of the stomach is taken up by glycerin when it is soaked in that liquid; in our experiment we shall employ such a solution of pepsin in glycerin. The experiment is made in the following simple manner.

We heat a chamber which can be closed to about 37° C. [98·5° F.], which is approximately the temperature of the body, and we place four glasses containing a little water in the warm chamber. In one of these glasses we place some of our pepsin solution, into another we pour hydrochloric acid, and into the third and fourth we put both pepsin and hydrochloric acid. As the substance to be digested we choose *fibrin* (about which albuminoid substance we shall learn more hereafter), and some hard boiled white of eggs. We put both of these substances into the first and second glasses, and only one of them into each of the third and fourth glasses (see fig. 13).

The process of dissolving albumen is not a chemical reaction in the ordinary meaning of that term, and it does not take place instantaneously, as so many chemical reactions do. As about half an hour must elapse before a noticeable quantity of the albumen has dissolved, we shall allow the experiment to proceed, and come back to it again at the end of the lecture, when we shall be able to convince ourselves that the desired result has been obtained.

The active substance in the stomach, which, as we know, is called pepsin, is only active in the presence of acids; but the substance called *trypsin*, which causes digestion in the intestines, is effective only in the presence of alkali; the contents of the intestines, therefore, show an alkaline reaction.

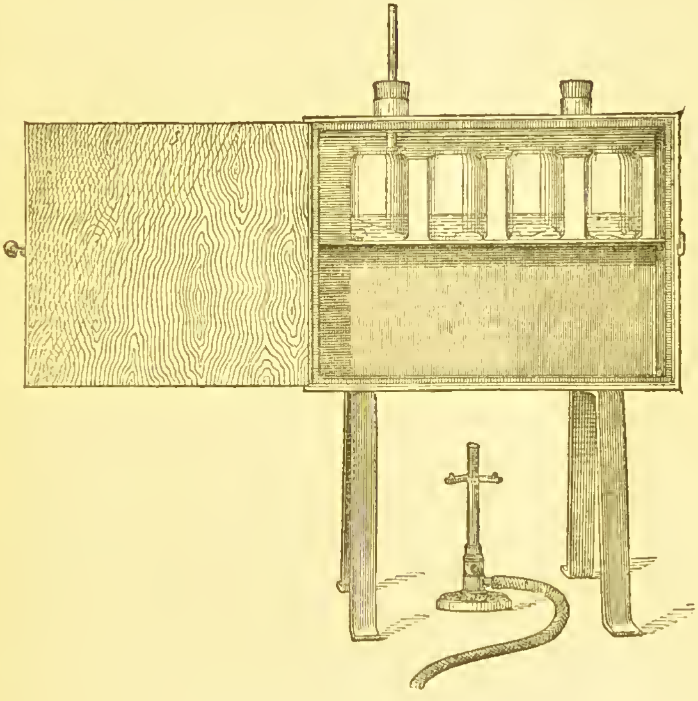

Fig. 13.

It is easy to understand that, when substances are got into solution in these ways, such substances pass into the blood, and are carried through the whole of the body. But there are other questions which press for answers, but which no one has yet succeeded in answering.

We have taken for granted, as self-evident, that processes of digestion go on in the stomach. But the stomach itself consists of flesh—namely, of albuminoid substances ; why, then, does not the stomach digest itself? how can it resist the action of the digesting fluid? We digest a goose's stomach with readiness ; and if you ascribe part of the digestibility to the process of cooking, you must remember that such an animal as a dog is able to digest an uncooked goose's stomach without trouble.

No certain answer has yet been found to the question we have proposed. We know that the secretion of the stomach is acid, and that the blood shows an alkaline reaction ; and we may suppose that the acid and the alkali neutralise one another in the coats of the stomach, and that the process of digestion is thus put an end to. But we cannot decide at present whether this is actually the cause or not.

There are many other unexplained problems connected with the process of digestion. Not to be tedious, let us select only one of these. Where does the stomach get the intelligence which enables it to select from the food all those things that are required by the body as a whole? We may very well suppose that the stomach looks after itself, and takes what it requires for its own sustenance from the food-stuffs that come into it. But how does the stomach know what quantity of phosphate of lime the bones require for their existence, and what the brain requires? How does the whole digestive apparatus find out how much nourishment must be given to the blood to keep up the increase of the body till the twenty-second year, and no longer?

But we are coming nearer to the difficult problems of physiological chemistry, and that is a domain into which we cannot enter here.

To be frank, we cannot say exactly what hunger or thirst is. One man feels hunger more in his throat, another more in his stomach. Nature has, however, taken care that when hunger assails us we should know that this disagreeable sensation can be removed by taking food; and as regards the choice of food she has left us plenty of room for selection.

Looked at chemically, food-materials may be divided into three main classes: the albuminoids (in addition to gelatin); the fats; and the carbohydrates (starch and sugar).

The albuminoids are substances which contain nitrogen; their composition is very complicated. They are formed, naturally, in plants (see p. 60), whence they find their way, with other food-stuffs, into the animal body. Other, very complicated, albuminoid substances are built up from these in the animal body; and having performed their proper functions, they finally leave the body, in the urine, in the form of a substance called *urea*, which is extremely rich in nitrogen and has a comparatively simple composition.

The name *albuminoids* is derived from egg-albumen; but in the course of time it has received a very wide connotation, which we have already more accurately defined, and has come to be applied both to albumen-like bodies which are soluble, and to similar bodies which are insoluble, in water. The albuminoids which are soluble in water—the albumen of eggs, for instance—are coagulated by boiling. This change is a very remarkable one. At any rate, there is not one of the many substances that have been made artificially by chemists in the course of time which exhibits this property ; there is little hope of being able to build up substances in the laboratory which shall be coagulable, and the artificial preparation of albumen is as yet quite out of sight.

The most important albuminoid of milk, which is called *casein*, is not coagulated by boiling ; but if the slightest trace of acid be present in the milk the casein separates out in flakes. This separation is made visible to you when I add a few drops of vinegar to some milk. Milk goes sour, apparently spontaneously, in warm, summer weather, and curdles whether you will or not. The reason of this souring is as follows. Besides containing about 3 per cent. of casein, milk also contains about 4 per cent. of a sugar called *milk-sugar* ; this sugar, like most other sugars, can ferment—that is to say, it can be transformed under definite conditions into other substances—without a specific chemical action.

No fermentation can occur without the presence of certain organisms—fungi, or bacilli, as they are called to-day ; these are everywhere in the air, but they are active only under certain suitable conditions. The lactic acid bacillus, which is so called because it changes milk-sugar into lactic acid—we shall meet with this organism more than once in the course of these lectures—begins to act on milk at a temperature between 20° and 30° C. [68° and 86° F.]; milk therefore curdles, by the formation in it of lactic acid, only on warm days.

When milk curdles by souring casein separates from it. Milk can also be curdled intentionally by means of rennet; and the substance which separates is used as a food-stuff, after being properly manipulated, and is called cheese. Rennet is a ferment analogous to pepsin; this ferment is not, however, present in all stomachs, but it is found especially in the mucous membrane of the fourth stomach of the calf. Because of the importance of milk as a nourishing food for children, many attempts have been made to preserve this liquid for a lengthened period—in other words, to prevent it from going sour. Soxleht's apparatus is now used in many families for this purpose. In this process milk is heated in a closed flask to 100° C. [212° F.]; all the bacilli in the milk are thus killed, and also all other bacteria which might bring about putrefaction. As long as the vessel is kept firmly closed, bacilli cannot fall into the milk from the air, and hence neither souring and curdling nor putrefaction can occur.

However, milk which has been boiled in this apparatus is not quite the same as unboiled milk. The casein, the fat, the milk-sugar, etc., are unchanged; but that portion of the albuminoids, other than casein, which is soluble in water—and which amounts to about 6 per cent., that is, to about one-sixth of the total albuminoids—is coagulated by the boiling, and is thus made more difficult to digest.

Besides those albuminoids which coagulate, some by heat and some by addition of acids, there are other substances of this class which remain dissolved as long as they are in a living body, but solidify very soon after they are withdrawn therefrom. Substances of this kind exist in blood; and when blood is exposed to the air it soon separates into a solid and a liquid portion. The solid, red mass becomes colourless when it is washed with water, and the washed substance is called *fibrin.* It was fibrin that we employed in our experiments on digestion, because this substance has been found to be readily peptonised when digested artificially, and hence it is very suitable for such a lecture experiment.

The liquid which remains when fibrin is separated from blood is called *blood-serum.* It has been discovered recently that if animals are treated with the poisonous substances which diphtheria-bacilli produce in the media wherein they are cultivated, the serum of such animals exerts a healing effect on human patients suffering from diphtheria.

We shall not go deeper into the very difficult subject of the classification of the albuminoids. It should be noted that, speaking chemically, flesh belongs to the albuminoids, inasmuch as it is a very complex aggregate of nitrogen-containing substances.

One thing only is to be remarked. Albuminoids occur in the vegetable kingdom; wheat-meal contains about 10 per cent., grass from 2 to 3 per cent., and hay from 10 to 12 per cent., of albuminoids.

It is customary nowadays for farmers to buy artificial fodder when they have not raised a sufficient quantity of natural fodder for their cattle; on account of their great nourishing power such artificial fodders are known as feeding-stuffs. Most of these feeding-stuffs consist of the cakes that remain when the oil is pressed out of certain plant-seeds which are rich in that substance; [hence the name *oil-cake*]. These substances are remarkable for the large quantity of albuminoids they contain; this may amount to 50 per cent., as, for instance, in cakes made from the seeds of the sunflower. In order to avoid the application of the term albumen to a constituent of plant-seeds, which may seem somewhat strange to ordinary ears, it is customary to speak of these substances as *proteïds*, a nomenclature which was introduced into the chemistry of the albuminoids in the forties of this century.

Let us now see what are the results of our experiments on digestion (see p. 54). Looking at the contents of the first and second glasses, we see that neither the fibrin nor the hard boiled egg-albumen has been at all changed by digestion with pepsin only; that the fibrin has been caused to swell up, but has not been dissolved, by the hydrochloric acid only; while the acid has produced no change in the hard boiled egg-albumen. Now looking at the contents of the third and fourth glasses, we see that the mixture of pepsin and hydrochloric acid has so acted on the fibrin that that substance has gone entirely into solution; if we examine this solution more narrowly we shall find that the fibrin has been changed into a peptone, which, as we know, is a soluble albuminoid. The hard boiled white of eggs, if not dissolved and changed into peptones, has certainly been much acted on by the mixture of pepsin and hydrochloric acid. This substance is not so easily digested as fibrin; had we allowed the experiment to continue for a longer time we should have got the whole of the egg-white into solution.

In actual digestion things will of course proceed in a similar way. Hard white of eggs is rightly regarded as not easy to digest; but although the process of digestion occupies more time in this than in some other cases—than, for instance, in the digestion of flesh—hard boiled eggs are not harmful to a healthy stomach, but they are not to be recommended when one's stomach is out of order.

Before leaving the albuminoids we must just glance at the substance called *gelatin.* The cartilage, the bones, and all the ligatures of the animal body contain substances which dissolve in water when boiled therewith for some time and form a liquid which gelatinises as it cools. Gelatin is obtained by drying such gelatinised solutions. As thus prepared gelatin is used as a glue.

Gelatin contains a large quantity of nitrogen. The following analyses show that the percentage of nitrogen in this substance does not differ much from that in the more characteristic albuminoids; gelatin may, indeed, to some extent be substituted for albumen in foods, in some of which—for instance, in that prepared by boiling bones—it is contained along with albumen:

	Egg-albumen.	Plant-albumen from wheat.	Gelatin.
Carbon	52·25	54·3	50·1
Hydrogen ...	6·90	7·2	7·5
Nitrogen... ...	15·25	16·2	17·5
Sulphur ...	1·93	1·0	—
Oxygen	23·67	21·3	24·9
	100·00	100·0	100·0

LECTURE IV.

Mixed diet. — Butter. — Margarine. — Starch. — The sugars.—Ripening of fruits.—The diet of diabetic patients.—Fruit-sugar.—Bonbons.—Burnt sugar as a colouring material.—Cane sugar.—Bounties on exported sugar.—Saccharin.—The absorption of food.—Common salt.—Iron.—Importance of cooking.—Soups.—Bread making.—Boiling potatoes.

THE albumen which is consumed in food serves to replace that which is used in carrying on the vital functions of the body. But other kinds of nourishment besides albuminoid substances are required to supply the energy which the body constantly requires, for instance, for moving itself as a whole, or for moving parts of itself—say for continuing the action of the heart—and also for constantly maintaining the temperature of the body, by the burning of carbon finally to carbonic acid, at that point which is necessary for the proper performance of its functions.

The simple replacement of the carbonic acid which is expired in the breath (see p. 10), for instance, does not necessitate the presence of nitrogen in food, inasmuch as nitrogen takes no part in this process.

Now we know that nature has given us a fairly wide choice in the matter of food-materials, and the quantity of carbon in a diet very rich in nitrogen may suffice for all the needs of the animal body. This is proved by the case of beasts of prey, some of whom consume only flesh, which has been shown, by experiment, to contain extremely little non-nitrogenous food-materials, to be, indeed, an almost purely albuminoid diet.

A pure albuminoid diet is certainly not required for the proper maintenance of the body; we much prefer a mixed diet—that is to say, we take various dishes in the course of a day, which dishes contain sufficient albumen to make up for what is used in the body, and also sufficient non-nitrogenous nourishment to carry on the work of the body and to maintain the bodily temperature; and we supply our want of liquids by adding water or some liquid form of nourishment.

The non-nitrogenous food-stuffs belong to two chief classes—the fats and the carbohydrates. As the fats and the carbohydrates do not contain nitrogen, these substances take their place among the food-stuffs by virtue of the carbon which they contain. Fats are formed chiefly in animals, but to some extent also in plants; plant-fats are generally called oils by those who are not chemists. On the other hand, only very small quantities of carbohydrates are found in animals; all the substances of this class which are used as foods come from the vegetable kingdom.

The fact, so often noted with astonishment by travellers, that the Greenlanders consume large quantities of blubber and fat, will readily be understood from what has been said. As these people cannot till the fields, and therefore can have neither meal nor sugar, etc., for consumption, they are obliged to supply all their needs in the way of non-nitrogenous food by consuming the one kind of such food—fat—which they can get. We enjoy both kinds of non-nitrogenous foods. We consume fats in the form of fat or butter, and carbohydrates in the form of bread (or other preparation of flour), potatoes, and the like. Farther south plant-fats, such as olive oil, are used as foods. Man has known instinctively how to draw supplies of fats and carbohydrates from his surroundings.

A very large part of the fats consumed in our latitudes is consumed in the form of butter, which is made from milk. When milk is allowed to stand it gradually separates into two layers, the lighter fat-globules floating upwards and forming the cream, and the milk deprived of fats—or the skim milk—remaining below. When the cream is violently agitated, as is done in churning, the single fat-globules gather together and become solid, and so form butter.

The somewhat high price of butter led to attempts to fabricate an artificial substitute. These attempts were successful in France about the year 1870. This substitute for butter is made from ox-tallow. The tallow is melted; the liquid is completely separated from pieces of skin by filtration; the clear liquid is mixed with a little salt, and is allowed to stand for twenty-four hours at the temperature of 25° C. [77° F.], whereby it is partially solidified, after which it is pressed in an apparatus kept at 25° C. The residue in the presses, which consists chiefly of stearate of glycerin, is used for making stearin candles (see p. 21), while that which flows from the presses is employed as a cooking fat under the name of *oleomargarine.* If this liquid oleomargarine is to be made into artificial butter, it is mixed with about half its weight of cows' milk, and about the same quantity of water is added, containing a little of the soluble constituents of powdered cows' udder. By vigorous beating this mixture is caused to separate gradually into two parts, one of which is the artificial butter, and the other is an aqueous liquid. It will be evident, from what has been said already, that there is no fault to be found with carefully prepared artificial butter as a nourishing food.

The fat which is left in fresh animal flesh by the butcher is most generally used for making artificial butter ; and after that preference is given to the fat of pigs, large quantities of which are sent into the market from North America.

Let us now consider the carbohydrates.

The name *carbohydrates* is derived from the proportion in which the elementary constituents of these substances are contained in them. This class of bodies includes starch powder, the sugars, and other similar substances with which we shall become acquainted in another lecture. The sugar which is found in grapes, and which is generally known as *grape-sugar*, has the following composition, stated in atoms.

Grape-sugar.

6	atoms of	carbon	(represented	by the	letter	C).
12	,,	hydrogen	(,,	,,	,,	H).
6	,,	oxygen	(,,	,,	,,	O).

Using the contractions already explained (see p. 24), this composition is expressed by the formula

$$C_6H_{12}O_6.$$

The proportion of the atoms of hydrogen to the atoms of oxygen is as 2 is to 1, which is the same as the proportion of the atoms of these elements in water whose formula is H_2O.

It used to be supposed that these substances were composed of carbon united with water; hence the name *carbohydrate* was given to all of them, for in all the proportion of the hydrogen atoms to the atoms of oxygen is as 2 is to 1.

Very remarkable researches, which have been brought towards completion only very recently, have shown that the conclusion drawn from the analytical results—namely, that those substances are compounds of carbon and water—is not justifiable. The name carbohydrate is therefore quite inapplicable; nevertheless, it is retained as a convenient general designation for this class of bodies.

Starch, which is the most important carbohydrate, is found everywhere in the vegetable kingdom. The chlorophyll-containing granules of leaves are able to make use of the carbonic acid of the air for building up starch (see p. 38). Starch, therefore, is found in all the green parts of leaves. This substance, starch, at last accumulates in those organs of plants which serve as storers of reserve material (see p. 102). We find these especially in the bulbs and roots, in the fruit, and in the seeds.

Whatever be the source of the starch, the composition of it is always expressed by the chemical formula $C_6H_{10}O_5$; but the granules of starch obtained from different plants show noticeable differences when looked at under the microscope.

Starch is generally prepared from potatoes, wheat, rice, or maize. The process consists, in the main, in rasping the potatoes, etc., along with water, and passing the product through fine sieves; the coarser parts remain on the sieves, while the starch granules pass through the meshes in suspension in water.

The turbid liquid that is obtained in this way is allowed to settle in barrels, and the starch gradually falls to the bottom. The liquid is drawn off, the deposited starch is drained, and finally dried at a temperature which must not be too high, as if moist starch is heated to about 50° or 60° C. [120° to 140° F.] it is completely changed, its structure disappears, and it becomes what we call paste.

Starch is spoken of as potato-starch, wheat-starch, etc., according to the name of the plant from which it has been obtained. Starches which come from foreign countries are generally called by special names, such as *arrowroot*, which is obtained from the roots of various tropical plants, and different specimens of which are not identical.

Sago-starch is somewhat different from these other starches. It is obtained from the pith of certain palms by grinding in the same way as potato-starch is made. After being completely dried the substance is allowed to fall through sieves on to warm metallic plates. This causes a partial conversion into paste of the exterior parts of the granules, and these gather together into little round balls that are sent into the market under the name of *sago*.

The following analyses show the quantities of starch in the seeds and tubers that are most commonly consumed. The analyses represent the composition of ground corn, as it is only in this form that the grains of wheat, rye, etc., are used as foods :

		Finest wheat-meal.	Rye-meal, mean composition.	Potatoes, mean composition.	
	Water	14·86	15·06	75·48	per cent.
	Albuminoids	8·91	11·52	1·95	,,
	Fats	1·16	1·79	0·15	,,
Carbohydrates.	**Starch**	**65·93**	**62·00**	**20·69**	,,
	Sugar	2·23	0·95	—	,,
	Gum and Dextrin	6·03	4·86	—	,,
	Cellulose	0·33	2·11	0·75	,,
	Ash	0·55	1·71	0·98	,,
		100·00	100·00	100·00	

All sorts of starch have the common property of being coloured blue by traces of iodine. We would not mention this occurrence were it not that attention is often drawn to it in the ordinary affairs of life. Linen is generally starched after it has been washed, to give it a better appearance—that is to say, some starch paste (starch boiled with water) is added after the ordinary process of washing has been finished; when the materials are then ironed the threads adhere together and the garment looks stiffer and more glazed. If a little iodine comes into contact with material that has been treated in this way—and this may very well happen, as tincture of iodine is a good deal used by the public—a blue coloration is produced; but this gradually disappears when the garment is washed again. A large quantity of iodine of course produces a brown iodine stain.

The analyses given above show a certain amount of *cellulose* in wheat and rye-meal and potatoes; this substance is also a carbohydrate, and its composition is expressed by the formula $C_6H_{10}O_5$; but as it is quite indigestible, it does not represent any nutritive element.

What about Cabbages?

We must now proceed to the consideration of the sugars. Although a great many kinds of sugar are found in nature, yet the varieties of sugar are not so numerous as the different kinds of starch. Starches and sugars are nearly related to one another, and starches are converted into sugars, especially into grape-sugar, with the greatest ease.

We may often notice this change taking place in ordinary life. Unripe fruits have not a sweet taste; but some of them—for instance, strawberries—acquire this taste in a few hours. The cause of this process is to be found in the change of a portion of the starch contained in the strawberries into sugar. This change occurs not only when the fruit ripens, but it may also be brought about by cooling the fruit below 0° C. [32° F.]. For instance, we know that the taste of potatoes which have been frozen is sweet, although not altogether agreeable. The cause is the same in both cases.

The rapid conversion of starch into sugar may be demonstrated by adding powdered starch to some water that contains a little acid, say hydrochloric acid, and boiling for a short time; a portion of the starch is thus converted into sugar, and the presence of sugar may be shown by making use of the following chemical reaction. If we add caustic soda and copper sulphate (blue vitriol) to some water we get a bluish precipitate of copper hydroxide; and if we now boil for a little this bluish precipitate is changed into black oxide of copper: the presence of starch does not alter this reaction. But if we boil some starch with a little hydrochloric acid, and then add caustic soda and a solution of copper sulphate to this liquid, we do not obtain a blue precipitate, but a sky-blue liquid; if we now boil this blue liquid there is formed in it not a black, but a red, precipitate of cuprous oxide (protoxide of copper). This reaction is characteristic of grape-sugar.*

The sugar that is produced in this way from starch is grape-sugar. The chemical process is easily understood. That starch may be changed into sugar it is only necessary for the starch to combine with the elements of water. Thus

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* When this reaction is applied to urine it enables the practitioner to diagnose diabetes, as diabetic patients excrete grape-sugar.

From what we now know it is easy to understand the reason for the special diet which is prescribed to such patients. Except in the most advanced stages of diabetes, when all the material transformations that normally occur in the body are thrown into complete disorder (and such changes we shall not of course consider here), albumen cannot be changed into sugar; there is also no intimate chemical connection between fats and sugar; but we have just convinced ourselves that starch and sugar are very closely related. If, then, a diabetic patient is put on a diet of albuminoids and fats—if he consume flesh, eggs, butter, and the like—he will not excrete any sugar. But if he is allowed to consume dishes prepared from meals or potatoes, or such vegetable products, all of which contain much starch, these will give rise to the excretion of greater or smaller quantities of sugar; he should therefore be bidden to abstain from such foods as far as he possibly can.

In the less serious stages of the disease the use of certain quantities of starchy foods may be valuable for the general nourishment of the body of the patient, and for this reason he may be allowed to consume a little, but only a little, wheaten or rye bread, etc.

Starch which consists of	takes up water	and produces grape-sugar, which consists of
6 atoms of carbon		6 atoms of carbon.
10 atoms of hydrogen	2 atoms of hydrogen	12 atoms of hydrogen.
5 atoms of oxygen	1 atom of oxygen	6 atoms of oxygen.

The change may be represented more shortly in this way:

$$C_6H_{10}O_5 + H_2O = C_6H_{12}O_6.$$

There are certain substances which stand between starch and grape-sugar; the best known of these is *dextrin*, which can be prepared, among other ways, by heating starch to 170°—200° C. [340°—390° F.]. Dextrin is much used as a substitute for gum arabic.

Sugar is manufactured by boiling starch with acids, and is sent into the market under the name of starch-sugar, or, more generally, *glucose*. As it is very difficult to cause this sugar to crystallise, even when working in the laboratory on a small scale, commercial glucose presents the form of a syrup. This syrup forms a passable substitute for honey. It is much used for the preparation of gingerbread biscuits; but its chief application is in the making of *bonbons*, as when these are made by using glucose they are not so hard as if cane sugar were employed.

Glucose is also employed for making sugar-colouring. If one heats a little glucose in a glass vessel till it becomes dark brown, allows it to cool, and then adds some water, the colour changes to the yellowish brown tint of cognac; on further standing the colour deepens and becomes that of dark coloured beer, although, as we shall learn hereafter, the colour of such beer is not produced in this way.

As this sugar-colouring is quite harmless, it is very useful for tinting articles of food or confectionary.

Cane sugar, which is used by us every day and comes as a sweetening into every meal, is of more interest to us than glucose, which we only occasionally see as such in our ordinary way of living. Before the introduction of cane sugar honey was the only sweetening material; and it is very doubtful whether we should now be pleased with the sweetened dishes, tasting of honey, which the ancient Romans set before their guests at their feasts, or with those honeyed preparations that were consumed in the earlier Middle Ages in the patrician houses of Nürnberg.

As its name implies, cane sugar is the produce of a cane-like plant; it is got from the sugar-cane. This plant grows only in Southern climates; the knowledge of it was brought to Europe by the Crusaders. At first the sweet juice of the plant was used in the form of a syrup; the preparation of the solid sugar dates from the year 1400. About one hundred years later began the process of refining cane sugar, by dissolving the crude sugar in water, clearing the solution, and allowing the much purer sugar to crystallise out, after boiling.

As soon as cane sugar had become an easily transported article of commerce the manufacture of it advanced rapidly, and the sugar-cane began to be cultivated in every country where the climate allowed of its growth. The plant was introduced into Central America, especially into the West Indies, about 1500; and after about six years so much sugar was manufactured there, by the labour of slaves shipped from Africa, that the cultivation of the cane almost ceased in other parts of the world, even in the East Indies where the climate was well suited for this purpose. The plant was introduced at an early date into Sicily by the victorious Arabians; and that island is the most northern country where the cultivation has been attempted. But the industry has disappeared from Sicily, and from Europe in general, since the American over production began.

In 1747 the Berlin chemist Marggraf discovered that the same sugar which is obtained from the sugar-cane exists in beetroots. This discovery was of the greatest importance to European agriculture, as it introduced a new, and for a long time very profitable, crop.

Marggraf was perfectly conscious of the far-reaching character of his discovery. A kinsman of his, named Achard, very soon endeavoured to manufacture sugar from beetroots on a large scale, but without success, because the cheap colonial sugar made it impossible to run a paying factory in Europe at that time. But the state of affairs was altered by political changes. In consequence of the Continental blockade of the first Napoleon, the price of all colonial productions which had until then been imported into Europe by the English rose immensely, and this was especially true of sugar, the price of which rose to four shillings per pound. Under these conditions the manufacture of beetroot sugar was bound to be a paying business, and this business was eagerly undertaken.

The raising of the Continental blockade ruined most of the sugar factories then in work; but so much experience had been amassed in the manufacture, that at last this sugar gained a firm hold on the market in opposition to the colonial sugar, especially as the latter, being a very convenient object of taxation, was obliged to pay a high import duty.

The manufacture of sugar from beetroots has in the course of years become an enormous concern, and it has been brought to great perfection by the combined action of science and industry. The following figures make this very evident.

To obtain 100 lbs. of sugar there were required—

In the year	1836	1,800	lbs.	of beetroot.
,,	1842	1,600	,,	,,
,,	1857	1,200	,,	,,
,,	1871	1,100	,,	,,
,,	1894	750	,,	,,

Marggraf found that the beetroots cultivated in his time contained rather more than 2 per cent. of sugar. The percentage has been raised since then by the proper choice of manures, chiefly, as one might suppose, artificial manures, until from 14 to 16 per cent. of sugar is now obtained from beetroot.

In order to extract the sugar the beetroots are first of all crushed and rasped to a pulp, and all the sugar is then removed by treatment for several hours in what is called a *battery of diffusers.* The juice must then be evaporated. This process presents many difficulties, because if sugar-syrup is boiled for a long time the sugar is altered and becomes non-crystallisable. But the difficulties have been overcome by carrying on the evaporation of the sugar solution under a greatly reduced pressure, instead of, as in ordinary processes of boiling down, in open vessels; the syrup boils at a much lower temperature in an evacuated vessel than it would do in an open vessel. In the first lecture we had ocular demonstration of the pressure of the air (see p. 3). Suppose water is heated; before the vapour of the water can rise freely—that is, before the water can boil—the pressure of this vapour upwards must be sufficient to overcome the downward pressure of the atmosphere. Now if the air is removed from a closed vessel—say from a copper vessel, such as is used in the sugar factory—by means of an air-pump, the vapour of water in such a vessel will ascend much more easily than if the water were in an open vessel; and therefore water will boil in such a vessel at a temperature much lower than its ordinary boiling-point, which is 100° C. [212° F.].

The process may perhaps be more easily understood by considering the following fact. Water boils on the top of Mount Blanc at 85° C. [185° F.], because the height of the column of air which presses on the surface of the water is as much less than that of the air-column at the level of the sea as is the height of the top of the mountain above the sea-level.

The sugar-juice can be boiled down without any danger at the greatly reduced temperature obtained by using an apparatus from which most of the air has been removed. After sufficient evaporation and cooling, sugar separates from the liquid in crystals, which are then purified and sent into the market in the form of sugar-loaves. Animal charcoal (see p. 45) is made use of for effecting the complete decolourisation of the syrup.

The mother-liquor (see p. 52) from crystallised sugar is known as *molasses.* For a long time no method could be found for obtaining the sugar that remained in this liquid, but, by methods suggested by chemists about twelve years ago, the whole of the sugar can now be withdrawn from molasses.*

In connection with the sugars it will be well to say a word on the most recently introduced sweetening material, called *saccharin,* a name derived from *saccharum,* the Latin word for sugar.

Of the vast number of chemical compounds there are certain to be many with a pronounced taste ; the acids, for instance, take their name from the fact that the earliest discovered substances of this class had an acid taste. Bases such as potash or soda have a caustic, soap-like taste. Some salts, that is compounds of acids and bases, have a pure salt-like taste, others a bitter saline taste, etc., and some are tasteless. The tastes of the many compounds which do not belong to one or other of these three classes are almost infinitely varied. Omitting sugar, a few substances with a somewhat sweetish taste, such as *alanine*, have been known for long. But it happens that only one substance has been discovered, up till now, which is so extraordinarily sweet that one part of it is equal in sweetening power to 300 parts of sugar; this substance is saccharin. The chemical composition of saccharin is very complex; its systematic chemical name is *sulphobenzimide*.

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* We have more than once referred to the relations of sugar to taxation. These relations have changed much in course of time. So long as only colonial sugar came into consideration this sugar was a convenient subject for taxation—as tea, coffee, etc., are to-day—and the revenue derived therefrom was purely a customs duty. But when sugar began to be produced at home, the only course open to the state, if its revenues were not to suffer, was to impose a tax on sugar. The most convenient way of doing this is, without doubt, to tax the beetroots, determining the quantity that comes into each factory, and proceeding on the assumption that a certain quantity of beets will produce a certain quantity of sugar. If this is done a free hand is given to the manufacturer to work up the raw material in any way he pleases. But when so much sugar was manufactured that not only was the home demand satisfied, but sugar was also exported—that is, was purchased by foreigners—it was of course necessary to give back the amount of the tax on this sugar, in order that the home-produced sugar might compete on equal terms with cane sugar on which no tax is imposed in the country of origin. Then

Saccharin has no value as a food, quite independently of the fact that it is never consumed except in very minute quantities. It may be used for sweetening all sorts of things; but it has proved beneficial chiefly to patients suffering from diabetes, who are able by its help to enjoy the sweet taste of dishes which,

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began the era of export bounties, about which so much is said nowadays. Suppose the manufacturer had paid duty on the supposition that ten cwts. of beets would yield him one cwt. of sugar, and suppose he had improved his methods so that he obtained this same quantity of sugar from nine cwts. of beets, then if he exported the sugar he received back what he had paid on ten cwts. of beets, while he was paying only on nine cwts. in the form of exported sugar. In this way the original drawback became an export bounty. This arrangement acted as a powerful inducement to devise constant improvements in the methods of manufacture, as every improvement in the output of sugar was at once translated into hard cash in the form of an increased export bounty.

[The passage I have put into this footnote forms part of the text in the original.—Tr.]

before the discovery of saccharin, they were obliged wholly to renounce.

The advantages of sweetening dishes in this way should not be regarded as small, inasmuch as many foods are thus made more easy of consumption. For there is no doubt that emotional conditions play a part in the absorption of foods as well as physical needs. We continue to take only such means of nourishment as have been made agreeable to our palates in one way or another. It appears as if such condiments as salt, pepper, and mustard were required to rouse the digestive processes into activity. Indeed we go further than this; we regularly enjoy warm decoctions of coffee or tea, the nourishing value of which is *nil*, because we know by experience that these make easier the consumption of solid nourishment.

Spirituous drinks occupy a position between those things we consume for nourishment and those we consume for pleasure; and when we go more into detail we shall find that these liquids belong more to the latter than to the former class.

Experience teaches us that men fairly easily get accustomed to one kind of delicacy or beverage, so that the continued use of the same things either leads to satiety, or the wished for effect can be obtained only by increasing the quantity, with the result that excess is indulged in, and deplorable consequences follow. Hence it follows that there must be a considerable variety of dishes in a diet which is suitable for constant use, and that a careful selection must be made of the condiments which are added to give flavour and agreeableness to the dishes. Happily experience and daily habit have taught most housewives how to insure this result.

Refinement of cooking is by no means an improper object of endeavour. It is certainly as permissible as thousands of those other attempts after enjoyment which seek to make life more pleasant. By this we do not mean to advocate the consumption of dinners with an interminable array of different courses, but only to assert that the housewife does well when she takes care that what is put on the table is so prepared that it may be agreeable and may be consumed with pleasure.

It should not be overlooked that the preparation of food-stuffs on the large scale brings many advantages with it. In towns every one has his bread from the baker, and so he gets it fresh every day and with a good flavour; but in those country parts where each household must do its own baking the bread is generally stale, because it is impossible to prepare every day just what is wanted for the day's consumption. No one would assert that to bring about an improvement in the quality of bread for general consumption would be either wasteful or luxurious.

The preserved vegetables, which make it possible to enjoy vegetable diet in winter almost as cheaply as in summer, and also those preparations of meat and fish which are much used nowadays, belong to the substances we are now considering. Such things enable one to vary one's meals at a very small cost.

The well known saying about "*toujours perdrix*" shows very forcibly that a thing which in itself is extremely good eating, and when taken occasionally is peculiarly pleasurable to the palate, becomes altogether unenjoyable when consumed constantly for a long time.

It is not only human beings who object to monotony in diet; flesh-eating animals do the same. Rats certainly soon die if they can get nothing but boiled flesh; after a time they refuse to touch it, and prefer to starve rather than to eat the flesh. Birds seem to differ in this respect from flesh-eaters, as they may be fed in captivity for years on the same kind of grain or seeds without taking any hurt.

The analyses given on p. 69 of corn-grains certainly show us that these taken alone represent a mixed diet, and this may be the reason why they can be used as food for a long time.

To maintain life we require water and certain inorganic salts, besides albuminoids, fats, and carbohydrates. The only inorganic salt which we use directly in our food is common salt, which is a substance that we add intentionally to most dishes, and a substance which seems to have a specific beneficial effect on the animal body. We notice that where opportunity serves many animals resort eagerly and regularly to salt deposits.

The analyses of food-stuffs that have been given—and those which are to follow—show that the other salts which we require, such, for instance, as phosphate of lime for the bones, are contained in sufficient quantities in our ordinary foods. The total quantity of these salts is represented as ashes in the analyses. Iron is the only one of these inorganic substances which possesses much interest when a general survey is being made of the subject.

The quantity of iron required daily by a human being is extremely small; it may be taken as one-seventh of a milligram per kilo. of body-weight [about $\frac{1}{1000}$th of a grain per lb.]. This amounts to only about 3 grams per year for a person weighing 50 kilos. [about 45 grains for a person of 8 stone weight]; nevertheless it is well known that an insufficient absorption of iron leads to *chlorosis* and to many subsequent disorders. When one is in health the requisite quantity of iron is quite provided for by the food consumed; but in certain ailments, such as chlorosis in young girls, the power of the organism to assimilate iron from the food is so reduced that iron must be supplied artificially if the requisite absorption of that substance is to take place.

Now that we have considered separately the classes of substances that are required for the nourishment of our bodies we must deal with the dietetic value of cooking. Animal and vegetable food-stuffs differ much when looked at in this respect. The preparation of animal flesh is not very important so far as the nourishing value of the flesh is concerned. Raw minced beefsteak, made palatable by the addition of pepper and salt, is generally thought to be very nourishing, and this supposition is not unjustifiable. We certainly cannot enjoy the raw flesh of fish or birds; nevertheless the nourishing value of such flesh is not altered by boiling or frying. In the process of frying, however, the heating of the flesh with fat produces substances that have a pleasant odour and an appetising flavour, and which therefore make the consumption of the food easier. The five following analyses will elucidate what has been said.

	Water.	Proteïds.	Fats.	Extractive substances	Ash.
Fresh beef contains ...	70·88	22·51	4·52	0·86	1·23
After boiling it contains	56·82	34·13	7·50	0·40	1·15
Cooked beefsteak contains	55·39	34·23	8·21	0·72	1·45
Uncooked veal cutlets contain	71·55	20·24	6·38	0·68	1·15
Cooked veal cutlets contain	57·59	29·00	11·55	0·43	1·43

What especially strikes us in these analyses is that boiled beef contains less water than uncooked beef. This decrease in the quantity of water is due to the shrinking of the fibres of the beef brought about by the heating. But it is much more remarkable that the composition of boiled beef, or, as we may call it, soup-beef, should be so nearly the same as that of beefsteak; the percentage of albuminoids (proteïds) is indeed the same in both. There is, however, a difference in the quantities of extractive substances; in beefsteak these substances are nearly double what they are in boiled beef. In these analyses *extractive substances* mean those substances, other than proteïds and fats, which go into solution when the meat is boiled with water. Now these are just the substances that have an appetising effect on the palate. Such cooked foods as soup-beef, which contain but little of these extractives, taste insipid, and are not eaten with pleasure. Soup-beef, however, falls but little behind other kinds of animal food in respect of nourishing value; hence, if it is not overboiled, and it is eaten with condiments that make it more palatable, it is not to be despised.

And this brings us to inquire as to the best way of proceeding when soup is to be made from meat. Ought the meat to be put into cold water, or into hot water? Let us answer the question by an experiment.

We cover some minced beef with cold water and shake thoroughly—the beef is minced so that a large surface may be exposed to the action of the water. We now filter off the solid matter, and thus obtain a clear liquid coloured reddish by the presence of a small quantity of the colouring matters of blood. On now pouring this liquid into a beaker glass and boiling, we notice that its colour changes to grey—as the colouring matter of blood is unstable when heated—and that a great deal of a flocculent solid, which is found by experiment to be albumen, separates from the liquid. The cold water has thus withdrawn some soluble albumen from the meat, and this has of course coagulated when the liquid was boiled. Now when soup is skimmed the albumen which has become solid by boiling is removed in the scum, and so this amount of nourishment is sacrificed to the better appearance of the soup.

Now let us pour boiling water over another portion of the minced beef, and then boil for a short time. The meat very soon becomes grey, inasmuch as the colouring matter of blood cannot withstand the heat. We notice but few flocks of albumen floating in the liquid, and if we pour the liquid through a filter we obtain a clear fluid which does not become turbid when it is boiled.

In the latter part of this experiment the boiling water brought about the coagulation of the particles of albumen on the surface of the meat; the fine pores of the meat were thus stopped up, and but very little of the extractive substances found their way into the water.

The results of everyday experience confirm our experiment. If one wants to make a very well flavoured soup the meat must be put into cold water, because much extractive matter will thus be taken out of the meat; the meat that remains will, however, be disagreeably tasted: but if one wishes to get palatable meat hot water must be used; in this case the flavour of the soup will not be very good.

Generally speaking soups are required to be pleasant to the palate, rather than to possess a high nutritive value; the results of the analysis of a soup, prepared in the ordinary way from 500 grams [about 1 lb.] of beef and 190 grams [about $\frac{2}{5}$ lb.] of veal bones, will show that this requirement is fulfilled.

Water	95·18 per cent.
Proteïds	1·19 ,, ,,
Fats	1·48 ,, ,,
Extractive substances ...	1·83 ,, ,,
Ash	0·32 ,, ,,

Water is the chief constituent of this soup. The proteïds consist chiefly of gelatin, as the albuminoids have been coagulated by the heating and removed by skimming. The quantity of fat is of course inconsiderable. Still we consume soups willingly, and experience teaches us to ascribe to them a stimulating action on the nervous system; this action must be regarded as due to the extractives, and also to the potash salts, they contain. About half of the ash of the soup referred to in the foregoing analysis consisted of potash, and about one-fourth of phosphoric acid. The addition of herbs to soups serves of course only to improve the flavour.

The importance of boiling, baking, etc., is very different in the case of vegetable foods from what it is when animal food is concerned. Most vegetable substances, except fruits, are too hard to be eaten uncooked, and their organised tissues, to which they owe their consistence, must be broken up by cooking before we can use them as foods.

The different kinds of grains, which are the chief sources of our vegetable foods, must be broken up and freed from their husks by grinding in order that we may get at the flour within. But even then the flour is not suitable for human food, as the raw starch granules surrounded by their cell-coverings are only very slowly attacked by the digestive fluids. Quite a different state of affairs is brought about by heating the flour with water; the coverings of the cells are burst open, the starch escapes and passes into the pasty condition, when it is easily digested (see p. 68). The same purpose is served by the baking of bread, which process also brings about that peculiar sponginess of texture to which bread owes its great digestibility.

When flour is stirred up with water a very tough dough is obtained, because of the *gluten* in the flour. Gluten is a proteïd substance contained in flour which becomes of a glue-like consistence (hence the name) when moistened. If such dough is baked without further treatment a hard mass is obtained somewhat resembling ship biscuits. But if the dough is allowed to stand for some time it undergoes change; yeast-cells fall into it from the air, and these cause the sugar of the flour to ferment (a process to be dealt with immediately); the bacilli which cause lactic fermentation (see p. 58) also find their way into the dough, and produce lactic acid from the sugar. The lactic acid—and other acids chemically like it which are also produced in the dough—then acts on the starch to produce glucose, so that, even if the flour originally contained but little sugar, the yeast finds sufficient sugar to ferment.

Fermentation caused by yeast, by which process all spirituous drinks (to be considered in detail in the next lecture) are prepared, consists in the transformation of sugar (glucose) into carbonic acid gas and spirit, or, as the latter substance is called in chemistry, *alcohol*. The process may be represented as follows.

One molecule of grape-sugar, consisting of	produces two molecules of alcohol, each consisting of	and two molecules of carbonic acid, each consisting of
6 atoms of carbon	2 atoms of carbon	1 atom of carbon.
12 atoms of hydrogen	6 atoms of hydrogen	2 atoms of oxygen.
6 atoms of oxygen	1 atom of oxygen	

The process is presented more shortly thus:

$$\underset{\text{1 molecule glucose}}{C_6H_{12}O_6} \underset{=}{=} \underset{\text{2 mols. alcohol}}{2\,C_2H_6O} + \underset{\text{2 mols. carbonic acid.}}{2\,CO_2.}$$

One molecule of sugar (glucose) is transformed into two molecules of alcohol and one of carbonic acid gas. The carbonic acid gas is produced in the dough, and, as it cannot escape from the pasty mass, it causes the dough to *rise*—that is, to swell up in bubbles. When the dough is put into the oven the alcohol begins to evaporate, and this process also tends to loosen the bread and make it spongy. The heat also breaks up the cells of the moist starch granules which at once begin to become pasty. The outer portions of the bread become so hot that, when the bread is sufficiently baked, part of the starch is converted into dextrin; and, as dextrin has a somewhat pasty consistence (see p. 72), the starch granules, and other similar constituents of the bread, adhere together and form the crust that we are accustomed to see on the outside of loaves of bread.

If bread dough is allowed to stand in the air it becomes sour because of the formation in it of lactic acid and other similar acids.

It takes a considerable time for dough to ferment and become sour by the action of the yeast cells and bacilli that may fall into it from the air; but if fresh dough is mixed with a little dough that has become sour by standing in the air fermentation processes go on rapidly, as it is known that yeast cells and bacilli increase in number with extraordinary rapidity. When therefore one batch of dough has fermented a small quantity of it is always set aside in order to start the fermentative changes in the next batch. The flavour of sour dough is communicated to bread baked with such dough. Nowadays only black bread is made with sour dough, and the peculiar flavour of this bread is due to the dough used in making it. For making white bread it is preferred to use fresh yeast; this yeast was formerly obtained from the breweries, but to-day it is prepared for baking purposes by a special process. We shall leave the further consideration of this subject until we are speaking of fermented drinks, when we shall have a better grasp of the facts that are needed for its elucidation.

There are several substances which are used as substitutes for yeast in causing dough to rise. Carbonate of ammonia is sometimes used in household baking under the name of *salts of hartshorn.* This substance is composed of ammonia, which is a basic gas, and carbonic acid, which is an acid gas (see p. 51); the substance is a solid, but at the temperature of the baking oven it is resolved into its gaseous constituents, and these gases cause the dough to rise. Potashes, which is carbonate of potash (see p. 52), is also used. This solid salt is not decomposed by heat, but it gives off carbonic acid gas if it is mixed with sour dough. If the dough contains lactic acid this acid decomposes the carbonate of potash, forming lactate of potash, and carbonic acid gas which permeates the dough and causes it to rise. The action of this salt is effectual only when dough contains a considerable quantity of acid, for only then is sufficient carbonic acid gas produced to bring about the proper rising of the dough.

Reflection will show that the process of raising dough by fermentation must be accompanied by the loss of some nutritive substances, because fermentation always means destruction of sugar. Following Liebig, attempts have been made to obviate this loss by using baking powders whereby sufficient carbonic acid should be produced in the dough to cause it to rise and to become spongy.

Horsford's baking powder, for instance, which is much used, is a mixture of bicarbonate of soda and acid phosphate of lime; when this is kneaded into dough, the moisture in the dough induces a reaction between the constituents of the baking powder whereby carbonic acid gas is produced in such quantity that the dough becomes loose and spongy and ready for putting into the baking oven. Another baking powder consists of a mixture of tartaric acid and carbonate of soda with powdered starch. The action of this powder is similar to that of Horsford's powder; the starch is quite superfluous.

It remains now to say a word or two on the boiling of potatoes. Raw potatoes are much too hard to be consumed as food. Their hardness is caused by the husks which enclose the starch granules ; these husks are so connected together as to form what may be called the skeleton of the potato. This skeleton is so compact that the starch granules cannot be disintegrated by the digestive fluids in the human stomach. But when potatoes are boiled the husks are burst off from the starch granules, and these granules assimilate water and pass into that pasty state wherein the digestive fluids readily act on them with the production of sugar (see p. 70). In this way the potatoes assume that mealy appearance which we look for when we are to use them as food.

It will be easy for you to apply the principles laid down and illustrated in this lecture to the boiling and baking, etc., of other kinds of food-stuffs besides those we have mentioned especially here.

LECTURE V

Quantity of food that must be consumed, and nutritive values of the chief foods.—Fermentation.—Wine.—Cider and perry.—Champagne.—Mead.—Koumiss.—Beer.—Malt.—Spirits.—Dry yeast [German yeast].—Brandy.—Potato spirit.—Vinasse.—Spirit refining.—Absolute alcohol.—Methylated alcohol.—Liqueurs.

We come now to the important question, How much must a man eat to keep himself in full vigour? We know already that he ought to consume a mixed diet, consisting of both nitrogenous substances (albuminoids) and non-nitrogenous substances (fats and carbohydrates).

The greater or less abstinence of the vegetarians cannot make us forget this aspect of the question of food. As these people reject all albuminoids which are of animal origin, they must derive the nitrogenous food which they require altogether from plants. The analyses which have been put before you (p. 69) show that the proportion of the two kinds of food in plants is unsuitable, inasmuch as the quantity of carbohydrates so greatly preponderates that if sufficient albuminoid substances are to be obtained from that source it is necessary to take into the body at the same time far more than enough useless ballast in the form of carbohydrates. Of course it may be demonstrated that a man can exist on vegetable diet only. But the argument that such graminivorous animals as the horse or the elephant become very vigorous on a purely vegetable diet is not to the point, because nature has provided such animals with very long intestines for the better absorption of this diet. Many graminivorous animals have also several stomachs, and they masticate their food repeatedly.

While it is possible for the vegetarian to feed himself sufficiently by his method without too much trouble, it seems that a purely albuminoid diet can scarcely suffice for the nourishment of human beings. This is made evident in the cases of diabetic patients; such people ought not to consume anything of vegetable origin, but it is impossible for them to continue such a diet for a length of time. The almost total denial to them of food containing starchy matter is a source of lasting discomfort, and yet this is the only way of preventing those serious consequences which are otherwise certainly induced by this disease.

Many investigations have been carried out by Voit and Pettenkofer with regard to the quantity of nourishment that is required by a man daily. We shall quote a few of the results.

A hard worker requires daily, when he is working,

137 grams [about 2,100 grains] albumen, 173 grams [about 2,650 grains] fats, and 352 grams [about 5,400 grains] carbohydrates (starch or sugar).

The following numbers were brought out in the case of a young physician.

127 grams [about 1,950 grains] albumen, 89 grams [about 1,370 grains] fats, and 362 grams [about 5,600 grains] carbohydrates.

The following numbers represent mean values.

118 grams [about 1,800 grains] albumen, 88·4 grams [about 1,360 grains] fats, and 392·3 grams [about 6,040 grains] carbohydrates.

This quantity of albumen corresponds to 18·3 grams [about 282 grains] nitrogen, which is the quantity contained in the following weights of different foodstuffs.

	Grams =	Lbs.		Grams =	Lbs.
Cheese ...	272	0·6	Rice	1,868	4·12
Peas ...	520	1·15	Milk	2,905	6·4
Lean flesh ...	538	1·18	Potatoes ...	4,575	10·1
Wheat flour	796	1·75	Bacon	4,796	10·57
Eggs* ...	905	2	White cabbage	7,625	16·8
Black bread	1,430	3·15	Beer	17,000	37·5

The amount of carbon required daily by a man is 328 grams [about 5,050 grains]; this quantity is contained in the following weights of different foodstuffs.

	Grams =	Lbs.		Grams =	Lbs.
Bacon ...	450	0·99	Eggs	2,231	4·91
Wheat flour	824	1·81	Lean flesh ...	2,620	5·77
Rice	896	1·97	Potatoes ...	3,124	6·89
Peas ...	919	2·03	Milk	4,652	10·25
Cheese ...	1,160	2·56	White cabbage	9,318	20·54
Black bread	1,346	2·97	Beer	13,160	29·01

If we weigh out the quantity of carbon that our daily need demands, say in the form of wood charcoal, we are astonished to find that more carbon is required for twenty-four hours' heating of a man—if one may use such an expression—than for heating a small stove during the same time. It requires much more carbon than we generally suppose to maintain a human body—weighing, say, 70 kilos. [about 11 stones]—constantly at the temperature of 37° C. [98·5° F.] and to keep it in vigour.

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* A question is often asked as to the relative nutritive values of eggs and meat; the numbers in the tables show that, on an average, from 18 to 20 eggs are equal to 1 kilo. [about 2⅛ lbs.] of meat.

If the foregoing numbers are examined more closely they are found to confirm the ordinary experience of life for the most part, but in some particulars they go against our preconceived opinions. A diet of bacon and peas is generally thought to be very nourishing, and our tables show that we need not consume very much of these two together to supply our daily requirements. But if we desire to obtain sufficient nourishment from beer alone, the tables show that the nutritive value of this drink is so small that 17 litres [3¾ gallons] of it are required to furnish sufficient albuminoid substances, and 13 litres [2 gallons] to furnish sufficient carbon, for a day's requirements. Beer indeed can scarcely be called a food in the strict sense of that term; it must rather be regarded as a nourishing beverage, for the regular consumption of, say, a litre [1¾ pints] of beer per day will supply only about one-seventeenth of the total nourishment that we require.

Black, or rye, bread is the most perfect of all the foods mentioned in the preceding tables, for about 1½ kilos. [3⅓ lbs.] of that substance suffice to supply the total daily needs of a man. This explains the fact that labourers are very vigorous, although they are not so well nourished as the better to do classes, who, for instance, regularly eat meat. It is also easy to understand that, because of the constant use of his muscular activity, a labourer may possess a greater physical energy than those who are much better off in so far as change of diet is concerned.

The numbers which have been given exhibit the minimum quantities of nourishment required for the maintenance of the life of a man in full work. If any one falls below this he gradually collapses ; even those who are especially abstemious must consume at least this minimum quantity. Generally speaking a man eats much more than this, as it is quite impossible to maintain the theoretically correct proportion of the different kinds of food, and, moreover, habit plays a very important part in the matter.

The body assimilates what it requires for its existence, and what remains unused is excreted.

The statement we have made that a man can exist on 1½ kilos. [3⅓ lbs.] of rye bread consumed daily is of course purely theoretical, inasmuch as no one is able to live on rye bread alone for a length of time. But if the bread is made more palatable by the addition of butter, sausages, or the like, and if some other food is substituted every day for part of the bread, such a beverage as warm coffee being also consumed, then the statement applies completely to the feeding of the working classes.

Let us now consider fermented liquors more fully than we did in the last lecture.

If liquids that contain sugar, but not very large quantities of sugar, are exposed to the air they slowly undergo a very marked change in their properties, and this change is accompanied by the evolution of gas and the formation of a deposit which is known by the name of *yeast.*

The most striking feature of the change is that the liquids have become intoxicating. The process itself is known as *fermentation,* and the liquids that are produced are called fermented liquors.

Very concentrated sugar solutions do not undergo this process; such liquids have indeed preservative properties, and these properties are taken advantage of in the preparation of preserved fruit.*

It has already been pointed out (p. 58) that all processes of fermentation are caused by exceedingly minute living organisms which are present everywhere in the air. That organism which especially causes the change of sugar into alcohol and carbonic acid is called *Saccharomyces cerevisiæ.*†

The juice obtained by pressing grapes—called *must*—is the most easily fermented of all liquids. This juice contains the directly fermentable sugar *glucose,* and also all those substances which yeast requires for its growth; for as yeast is a living organism it can only thrive under definite conditions—for instance, in the presence of certain inorganic salts.

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* It should be noted that some sugars do not undergo fermentation, and that cane sugar and milk sugar belong to those which cannot be fermented directly. But when fermentation is set up in substances contained in a solution in which these sugars are present the sugars themselves are changed into fermentable sugars (see forward).

† We are not concerned here with a purely chemical reaction, but with changes that are connected with the life-processes of certain moulds; small quantities of other substances besides the main products are formed in these changes.

The liquid which is finally obtained by this fermentation is called *wine*.

We can tell from their flavour that wines made from different kinds of grapes contain very different quantities of sugar ; the quantity of alcohol in wines also varies, the upper limit being determined by the fact that when the quantity in a fermenting liquid reaches about 16 per cent. by volume the yeast dies. The following table, however, shows that some wines contain much more than 16 per cent. of alcohol by volume. To such wines alcohol has been added. The addition of alcohol is made partly for the purpose of making the wine keep better, and partly to give that particular flavour which the public are accustomed to connect with the name of the wine in question.

	ALCOHOL. Volume per cent.	FREE ACID. Per cent.	SUGAR. Per cent.
Silesian wine	5·5	0·80	—
Markobrunner (1882) ...	7·17	0·70	—
Liebfraumilch (1875) ...	11·55	0·63	—
Vöslauer Goldeck (1868)...	10·28	0·592	—
St. Julien (1865)	9·28	0·637	—
Chablis (1862)	9·30	0·494	—
Malmsey	7·50	0·900	36·40
Samos	14·96	0·73	7·68
Tokay, selected	10·76	0·60	25·34
Tokay, selected II. ...	14·84	0·62	8·20
Port...	19·82	0·33	4·82
Madeira	19·12	0·48	3·46
Malaga	15·12	0·39	15·50
Sherry	21·22	0·48	2·04

This table, which is made somewhat lengthy because of the many different kinds of wine we meet with, shows that every wine contains a little free acid, and also that the sugar in wines made from very sweet grapes is not wholly converted into alcohol, for the reason already mentioned, while there is no sugar in wines that are made from grapes poor in sugar. The sugarless wines are suitable for diabetic patients.

That fine aroma, which always becomes more apparent as wines age, called the bouquet of wines, is due to chemical compounds, all of which cannot be accurately defined, but among which are to be found certain *ethereal salts of organic acids*, a class of compounds the composition of which cannot be explained without a more profound chemical knowledge.

Cider and perry are alcoholic liquids prepared by pressing apples and pears and allowing the musts to ferment. As the juices of these fruits contain but little sugar the liquid obtained by the fermentation of these juices would be very poor in alcohol; sugar is therefore added to the musts before fermentation begins, and a proper amount of the most important constituent is thus insured in the fermented products. When currants or similar slightly sweet fruits are made use of, the addition of sugar is absolutely necessary if a drink is to be obtained with anything like a fair amount of alcohol in it.

Champagne is prepared from musts in many countries. The name is derived from the district of *Champaigne*, where this wine has been prepared certainly since the middle of last century.* Champagne is made by pouring the must, after the first energetic fermentation is over, into bottles, which are then tightly corked. As the after fermentation proceeds carbonic acid gas is generated, and as this gas cannot escape it gradually produces a considerable pressure inside the bottles. As many impurities are gradually deposited while the wine is fermenting in the bottles, the custom is to set the bottles on their heads when the second fermentation begins; when a workman then opens the bottle with its head downwards the first portion of liquid that is driven out carries these impurities with it. The bottles are then turned round, filled up with the so-called *liqueur*, and corked; fermentation again proceeds slowly, and the carbonic acid that is produced accumulates in the liquid. When the wire that holds the cork is removed the accumulated carbonic acid forces out the cork with a loud sound.

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* The word *sack* [*sekt* in German], which is so often used by Falstaff, means what we now call sherry. The actor Devrient brought the word *sekt* into fashion [in Germany] as a name for champagne in the beginning of this century.

The composition of the liqueurs on which the flavour of the finished wine so much depends is kept secret by the manufacturers.

In former days about one-fourth of the bottles were broken during the manufacture by the great outward pressure of the carbonic acid; but the glass industry is so much improved that not more than one bottle in a hundred bursts nowadays.

It is evident that wherever wine is made champagne might be manufactured; but the minute carefulness required in the processes must always prevent such champagne from becoming cheap, as we see in the prices of good German brands. Notwithstanding this we know that effervescing wines can be bought to-day at a very low price; but these liquors are not made in the same way as champagne, and indeed they have nothing in common with genuine champagne except the name. The manufacture consists in forcing carbonic acid—in the same way as is practised in making soda water—into light white wines which have been sweetened, if necessary, by adding sugar; when this is done the champagne is ready for the market.

A bottle of soda water can be bought to-day for a few pence; hence to charge wine with carbonic acid, and so to change it into so-called champagne, can cost but little, and the product can be sold very cheaply.

While the inhabitants of countries where the vine flourishes have been acquainted with wine since the earliest times, because its preparation almost forced itself on their notice, people living in more northern climes found other methods for obtaining alcoholic liquors, the use of which when once acquired seems never to have been abandoned by any race.

The dwellers in the lands north of the Alps, where the vine was introduced when these countries were conquered by the Romans, were long ago acquainted with *mead*. This drink is easily made; the starting-point is honey, which is very rich in sugar. The honey of bees does not ferment of itself because it is too concentrated; but if it is diluted, and exposed to air, fermentation is brought about by the yeast which falls into it, and the intoxicating liquor called mead is produced. To-day this drink is as good as forgotten; its taste, as one may easily convince oneself, is not very agreeable.

The drinking of *koumiss*, which is fermented mares' milk, has probably persisted since early days; but this drink is found only in Central Asia, whence it has never spread. We must say a little about the production of this drink, because when milk stands in the air in our climate it is not changed by yeast into an intoxicating liquid, but it becomes sour by the conversion of its sugar into lactic acid through the agency of the lactic ferment (see p. 58).

If milk is diluted with about ten times its volume of water, and some koumiss is then added to the diluted milk, the lactic ferment in the koumiss quickly causes the conversion of a part of the milk-sugar into lactic acid, and this acid then reacts with the rest of the milk-sugar and transforms that into a sugar which is directly fermentable (see the footnote, p. 96), and then fermentation into alcohol and carbonic acid begins.

Cows' milk can be converted into an intoxicating liquid by a similar process; and the preparation of this liquid has been attempted in many places on a large scale, but the manufacture has been given up, as the taste of the drink does not seem to suit the palates of Europeans.

People living in European countries where the vine will not flourish have learnt, in the course of time, to manufacture beer in place of mead and similar drinks; and beer has proved to be so much better tasted than the last mentioned alcoholic liquids that it has entirely driven these out of use.

The preparation of beer rests on the following principles. When seeds are placed in moist earth they soon put forth rootlets and then leaves. The rootlets are not, however, at once able to carry nourishment to the leaves, and so the supplies of starch flour and albumen stored in the seeds are drawn upon. As germination proceeds a substance is formed which converts the starch into sugar and dextrin, and the albuminoids at the same time become soluble. The substances held in reserve in the seeds having thus become soluble serve to nourish the plantlet until the roots have strengthened sufficiently to take this duty on themselves.

Experience has shown that barley grains are the most suitable of all cereals for beer making, the proper understanding of which process requires us to bear in mind what has just been said. Certain kinds of beer—Berlin *Weissbier*, for instance—can be made from wheat.

We shall confine our attention to beer made from barley, as that beer is much more generally consumed than any other, and it will then be easy to understand the preparation of other kinds of beer.

For the purpose of making beer barley is steeped in water and then placed in a cellar kept not too cold. The result is that the barley germinates without being put into the earth ; little roots are pushed forth, and the substance—called *diastase*—which has the property of changing starch into sugar is formed in the barley. The albuminoids in the barley at the same time become soluble in water.

When the rootlets have grown as much as experience has shown to be proper the barley is dried, and the substance so obtained is called *malt*. The drying may be done in an open place, but it is generally carried out by maltsters in kilns—that is, in highly heated apartments. The higher the temperature employed in the kilns the greater is the quantity of brown substances produced in the malt, and therefore the darker is the colour of the beer. If very dark coloured beer is to be made a portion of the malt is finally roasted in an apparatus like a coffee-roaster (cf. p. 72).

The malt is now crushed, and it is then run into tuns, where it is treated with water kept at 50° to 70° C. [120° to 170° F.], because the conversion of starch into sugar and dextrin proceeds most rapidly at this temperature. The liquor obtained by this process of *mashing* is called *wort*; it contains much sugar. But if this liquor were fermented without any other treatment a very disagreeable beer would be obtained. It has long been known that if a drink with a pleasant flavour is to be obtained from malt some bitter substance must be added. Hops are used everywhere for this purpose; they have been grown on the Rhine since the ninth century. Oak wood was used at one time in some parts of Germany for imparting a bitter flavour to beer; but such beer would not find favour nowadays.

The wort is boiled with hops; in this process some water is evaporated, and the wort thus becomes slightly more concentrated. The wort is now cooled by exposure in flat vessels, the process being hastened by mechanical contrivances. If the cooling is not done rapidly there is a danger of the fermentation proceeding in a wrong direction; for the lactic fermentation, that we have often spoken of, is liable to begin between 25° and 30° C. [77° and 86° F.], and if this occurs the beer is spoilt. The last process consists in allowing the liquid, cooled to the proper temperature, to ferment in large vats, after some yeast taken from a former fermentation has been added to it.

If the liquid were allowed to stand until sufficient yeast had fallen into it from the air the process of fermentation would be very slow and very uncertain; but if some yeast is added this yeast very quickly grows in the liquid, inasmuch as it finds there everything that is required for its nourishment. If the fermentation is allowed to proceed at a temperature of 12° to 15° C. [53° to 59° F.] the production of carbonic acid is so rapid that the bubbles of this gas carry yeast cells with them to the surface of the fermenting liquid. The beer produced in this way is called *high fermentation beer*; the flavour of such beer is not cared for [in Germany]. [English beer is generally made by high fermentation, the fermentative process being started at about 60° F. and carried up to 70° F. or more.]

In Bavarian breweries fermentation is carried on at from 6° to 8° C. [43° to 46½° F.]; the process goes on very slowly, and, as bubbles of carbonic acid form very gradually and rise one by one to the surface, the yeast sinks to the bottoms of the vessels. The product is called *low fermentation beer*; it keeps well, and its flavour is so excellent that it is sent all over the world, and wins golden opinions everywhere. But to make this beer drinkable it must be charged with carbonic acid gas, else it is flat and insipid. In order to charge it with the required quantity of carbonic acid the fermented liquor is placed in barrels, where a very slow but continuous secondary fermentation proceeds. The bungs are placed in these barrels a short time before the beer is to be drunk, and the carbonic acid, which continues to be produced but which cannot now escape, gradually accumulates in the beer. The amount of carbonic acid produced in this final process does not exceed about two-tenths of a per cent.

The following analyses show the quantities of the more important constituents in those beers which are in most demand; the numbers given are the mean results of many analyses.

	Water.	Carbonic acid.	Alcohol percentage by weight.	Sugar.	Ash.
Draught, or winter beer	91·81	0·228	3·206	0·442	0·20
Lager, or summer beer	90·71	0·218	3·679	0·872	0·223
Pale beer (*Weissbier*)	91·64	0·279	2·510	—	0·163
Porter	87·10	0·155	5·350	1·340	0·419
[Burton ale	79·6		5·90		
Scotch ale	80·45		8·50]		

We must now consider spirits and the liquors prepared from spirits.

Although the intoxicating effect of wine was known very long ago, yet it was not till the eighth century that the intoxicating principle was separated from wine; the separation was effected by the Arabians after they had discovered the process of distillation.*

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* To conduct a distillation seems to us a very simple process; yet in the days of antiquity, although people were much interested in nature, this method of separating a volatile liquid from a less volatile or a non-volatile substance was never employed. The ancients were more inclined towards that kind of natural philosophy which expected to answer all questions by speculative thought rather than to the genuine scientific investigation of nature by means of experiment.

It was known in ancient days that new and useful compounds could be obtained from various substances by what we should

When wine is distilled a clear, colourless, agreeably smelling liquid passes over, the most striking property of which liquid is its combustibility. This distillate was named *alcohol* by the Arabians. As this liquid seemed to be the spirit, or essence, of the wine it was called at a later time *spiritus vini.* The residue, with which nothing could be done, was called *phlegm*; hence Schiller's saying, "*Zum Teufel ist der Spiritus, das Phlegma ist geblieben.*"

As we are dealing at present with fermented liquors we will convince ourselves that there is a substance in beer, as well as in wine, which can be volatilised by boiling, and is combustible. Experiments have proved that the substance obtained in this way from beer is

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to-day call distillations. For instance, Pliny tells that an oil can be obtained from turpentine, which is a resin that exudes from many trees when their bark is cut, by boiling the turpentine with water in vessels over which woollen cloths are suspended, and then pressing these cloths; and uses for this oil must have been known, as it was prepared in considerable quantities. But no one hit on the idea of distilling turpentine resin in order to obtain an oil (what we now call turpentine oil), and the exceedingly incomplete method of getting the oil described by Pliny remained in use.

It may not be without interest to mention that camphor is obtained to-day by the inhabitants of the island of Formosa by a method the same as that described by Pliny two thousand years ago for making an oil from turpentine resin. The Formosans boil the wood of the camphor tree with water in vessels over which they place deep lids filled inside with brushwood. The camphor is volatilised with the steam, some of which of course escapes, and then, by reason of the partial cooling, solidifies on the brushwood in little pellets; the yield of camphor is equal to about 3 per cent. of the quantity of wood used. The purification of camphor by sublimation, whereby it assumes the appearance that is familiar to us, is conducted in Europe.

the same as that got from wine—that, indeed, it is alcohol.

We pour the contents of a bottle of beer into a flask, into which we then fit a cork carrying a glass tube about a metre and a half [almost 5 feet] long (see fig. 14). We now cause the beer to boil freely, and at the same time we bring a lighted taper to the opening of the glass tube; the alcohol vapour that is rising from the tube takes fire and burns with a long flame. The flame soon goes out, as there is but a small quantity of alcohol in a bottle of beer; nevertheless we have in this way, so to say, directly burned out the alcohol from the beer.

A great deal of spirit is distilled at the present time from wine; this spirit once sufficed for the total requirements of the world, but to-day it is used for making brandy. Beer, however, has never been used as a source of spirit, because a method of obtaining spirit from grains was discovered long ago, and this method is much less complicated than the brewing of beer.

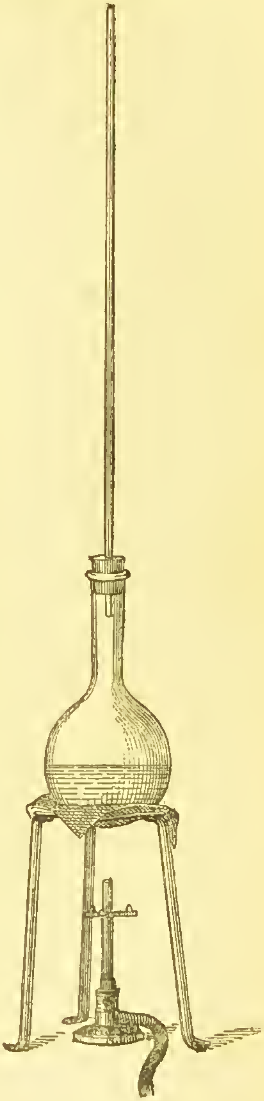
Fig. 14.

The process seems to have been invented in South Germany about the year 1500. The main points in the manufacture are as follows.

The raw material is rye, or a mixture of barley and rye. [Maize, rice, oats, sugar, and molasses are also made use of in this country; but barley is the substance generally employed.] The earlier stages in the manufacture are similar to the earlier stages of brewing; moistened barley is allowed to germinate; but the malt thus formed is not generally dried—as is done in beer brewing—but is subjected to further treatment.

The diastase of the malt, which brings about the change of starch into sugar and dextrin, is able to effect this change in a much larger quantity of starch than that which is contained in the malt. If the mashed rye [or barley], which has been boiled with water in order to set free the starch granules, is covered with water at about 60° C. [140° F.], and malt is then added, all the starch in the grain as well as that in the malt can be converted into sugar. The sweet liquid thus produced is then subjected to fermentation by means of yeast which the distiller prepares for his own use.

The preparation of this yeast is closely associated with the production of what is now generally called pressed or dry yeast (*Presshefe*) [German yeast], which is so convenient that it is almost always employed nowadays for bringing about fermentations. This yeast is used by the bakers of wheaten bread (see p. 86). It is also used in the kitchen, and for many other purposes. It has completely driven out the beer yeast, obtained from high fermentation beers, that was formerly employed, and which, besides containing so much water that it had the appearance of a grey liquid, often tasted bitter from the presence of substances derived from hops. The procedure is as follows. The fermentation whereby the yeast for use in making spirits is to be produced is carried on energetically, and is of the kind called high fermentation [that is, the yeast is carried to the top of the fermenting liquid by the stream of carbonic acid which is freely produced]. For this purpose a wort is prepared from one part malted barley and five parts crushed rye; yeast is added, and the temperature is kept up to nearly 30° C. [86° F.], which is much higher than that whereat fermentation is usually conducted. This very energetic fermentation brings about the production of much new yeast, part of which is used in the manufacture of spirits, and part for making dry yeast. For the latter purpose a workman skims off the masses of yeast from the surface of the liquid, and places them in a hair sieve floating on water in a barrel. The yeast cells pass through the sieve and gradually settle down to the bottom of the barrel, while all the coarser particles of solid matter remain in the sieve. When the yeast has settled the water in the barrel is drawn off, fresh water is added and is shaken up with the yeast, which is then allowed to settle again, and these processes are repeated several times. When the last lot of water has been drawn off the yeast is left as a fine mud-like deposit, resembling sculptors' clay. As water cannot be removed from this substance by pressing it the former custom was not to attempt the dehydration of this yeast mud. But an artifice has been devised which renders it possible to get the yeast so dry that it has the consistence of dough. About 20 per cent. of very dry starch is added to the yeast, and this starch absorbs so much water that a compressible pulp is obtained. Starch and yeast have no action on one another; yeast only acts on sugar, or on starch that is partly saccharified.

Presses have been constructed of late years by which yeast can be sufficiently dehydrated without the addition of starch, and dry yeast free from starch now comes into the market.

The sweet liquid prepared in the way already described from malt and mashed rye [or barley] is caused to ferment quickly, for the purpose of making spirits, by adding active yeast to it. The special method used in the fermentation is closely connected with the way in which the excise duties on spirits are levied. And the method which is most in harmony with the excise arrangements, which arrangements differ very much in different countries, is found to pay the best. The fermented liquid is finally distilled, and the distillate, which, like the spirit from wine, has an agreeable odour and flavour, is used for making various kinds of liquors. [Whisky is made by re-distilling, and so concentrating, this distillate; it contains from 60 to 78 per cent. alcohol by weight.] The residue left in the distilling vessels is known as *vinasse*; we shall speak of this immediately.

Spirits have been obtained from potatoes since about the year 1820. Although there is nothing of a spirituous nature in potatoes, yet when we remember what large quantities of starch they contain we at once see that an alcoholic liquid can be obtained from them by first converting their starch into sugar.

Indeed a glance at the numbers which represent the average results of growing potatoes and rye shows that much more spirit can be obtained from a given piece of land by raising potatoes than by growing rye thereon. About 1,600 kilograms of rye are harvested, on an average, from a hectare of land; and as rye contains about 65 per cent. of starch this is equivalent to about 1,040 kilograms of starch. But about 16,000 kilograms of potatoes are obtained, on an average, from a hectare of land; and, taking the starch in potatoes as not more than 18 per cent. on an average, this corresponds to 2,880 kilograms of starch. [One acre yields 12½ cwts. rye, equal to 8⅕ cwts. starch; and one acre yields 125 cwts. potatoes, equal to 22⅖ cwts. starch.]

When the process of manufacturing spirits from potatoes had once taken root it flourished exceedingly, especially in the Eastern Elbe provinces of Germany. These provinces were much enriched for many years by this industry; but the trade suffers to-day, as so many other trades do, from over production and the consequent depression in the price of the finished article.

We know that the starch granules of potatoes are enclosed in a husk (see p. 86). The custom in the manufacture of spirits was to set the granules free from the husks by boiling; but the experience of years has shown that all the granules cannot be so thoroughly deprived of their husks by this simple plan as to enable the diastase to convert them completely into sugar. That this transformation into sugar may be completed, which must be done if the maximum yield of spirit is to be obtained, it is now customary to boil the potatoes in closed vessels, and not, as formerly was done, in open vessels.

It is more difficult to cause water to boil in a closed than in an open vessel. Just as water boils much under 100° C. [212° F.] in a vessel from which the air has been removed (see p. 76), so the boiling-point is raised above 212° F. in a closed vessel, because of the pressure on the surface of the water of the water-vapour which cannot escape from the vessel. When the pressure on water is increased to four times that of the ordinary pressure, or, as is generally said, to four atmospheres, the water does not boil until it attains the temperature of about 150° C. [302° F.]; and the custom is to heat water with the potatoes under this pressure, and therefore to this temperature, in vessels called steamers. When the water in the steamers is boiled it of course attains the temperature of 150° C. [302° F.]; when this temperature is reached a valve in the bottom of the vessel is opened suddenly, and the contents are forced out into barrels placed ready to receive them. The excess of pressure is at once removed, and the water, some of which is enclosed in the cells of the potatoes, and which is too hot by 90° F., suddenly becomes vapour, for the formation of which the whole of the excess of heat must be employed. The result is that all the cells are thoroughly broken up, and the starch granules are set free so completely that they can all be acted on by the diastase and converted into sugar.

The next process consists in adding barley malt to the potatoes, mashed with water, and so converting the starch into sugar. This sweet liquid is then fermented by yeast in the way we have already described. Finally the liquid is distilled, and spirit is thus obtained.

The residue from the preparation of potato spirit, as well as that from the manufacture of spirit from grain, is known as *vinasse.* This substance is an excellent food for cattle; for a little consideration will show that, as only the starch is removed from the grain or the potatoes, the nitrogenous substances—that is, the albuminoids—remain as such in the residue. Now we know that these substances are exceedingly nourishing; hence the distilling of spirits makes it possible for the agriculturist to maintain a greater head of cattle than he could support on the same quantity of land without the aid of this manufacture, and in this way spirit making furthers agriculture.

The spirit obtained in the potato distilleries is, however, very different from that produced from wine or grain. The latter spirit can be used directly for making whisky, brandy, etc., as it has an agreeable flavour and odour. But the raw potato spirit must be purified in spirit refineries before it can be used as a liquor. For when potato wort is fermented there is produced, besides ordinary alcohol and carbonic acid, a series of other bodies (cf. note, p. 96), which, although they are classed by chemists among the alcohols, nevertheless act on the human organism in a way very different from that of ordinary alcohol. These substances are chiefly *amyl alcohols*, to give them their chemical name, and these alcohols, which are all classed together in ordinary language under the name of *fusel oil*, act as poisons; the smell of them is oppressive and causes choking. They must therefore be removed from the raw spirit; this removal is effected on the large scale in the following way.

The raw potato spirit usually contains about 80 per cent. alcohol and 20 per cent. water, together with fusel oil dissolved in these. If water is added until there is about 50 per cent. of alcohol in the liquid, the fusel oil, being no longer easily soluble in this diluted spirit, separates in very fine drops which cause the liquid to become turbid. The liquid diluted to 50 per cent. of alcohol is filtered through wood charcoal; the fine drops of fusel oil adhere to the charcoal, and are thus removed from the liquid. At the same time the charcoal removes the colouring matter and the substances which impart an objectionable odour to the alcoholic liquid (cf. p. 45).

The filtered alcoholic liquid is now brought to a percentage of 96 per cent. alcohol, by a method based on the following principle.

We remember that we found it possible to burn out the alcohol from beer, after a long glass tube had been attached to the flask wherein the beer was boiling. No explanation was given at the time of the reason for using so long a tube, because to stop then and explain would have taken attention away from the main point of the experiment; the tube was made long in order that the alcohol vapour might be completely separated from the water vapour. Had we attempted to set fire to the alcohol vapour at the mouth of the flask we should have failed, because the vapour of alcohol was mixed with so much water vapour at that point that the mixed vapour would not have ignited. But a separation of the vapours was effected by causing them to pass through the long tube, inasmuch as the heavier water vapour fell behind the comparatively light vapour of alcohol, and the latter issued from the upper opening of the tube mixed with so little water vapour that the alcohol took fire when a light was brought to the end of the tube. Spirit is made as concentrated as possible, by the use of this principle, in order to save cost of carriage; this is done by fitting to the distillation vessel a long cylindrical apparatus adapted internally for the purpose of separating the vapours of alcohol and water. Spirit obtained in this way never contains more than 96 per cent. of alcohol, as the remaining 4 per cent. of water is chemically combined with the alcohol.

It is only within the last hundred years that alcohol of 100 per cent., that is, quite free from water, has been prepared. This is done by adding burnt lime to the 96 per cent. spirit; the burnt lime is slaked by the water in the spirit, that is, the water enters into chemical union with the lime, so that when distillation is again carried out the water is retained by the lime, and *absolute alcohol*, that is, alcohol of 100 per cent., passes over.

This is the place to mention *methylated spirit.* As alcohol and alcoholic drinks are used as beverages they are favourite subjects for taxation in all countries. But the manufacture of spirits is advantageous to the farmer, not only by giving him spirit itself, but also by providing him with a valuable fodder for cattle in the form of the residues from the processes of distillation. It cannot be to the interest of the State to place hindrances in the way of a manufacture which is so advantageous to the farmer, provided the State can arrange the tax so that it shall fall upon the spirit consumed as a beverage, and place an obstacle in the way of excessive drinking. Why, for instance, should the State tax spirit to be used for heating purposes? It does not tax wood or coal.

Some means must be found for insuring that spirit meant for heating purposes, or for use in various industries, cannot be consumed secretly as a drink. Spirit must be robbed of those properties for which people drink it; its nature must be changed.

This purpose is effected by adding substances which do not alter the combustibility, etc., of the spirit, but by their odour and taste make the spirit undrinkable, and which cannot be removed except by those who have considerable chemical knowledge and have also suitable apparatus at their command.*

[*Methyl alcohol*, or, as it is more commonly called, *wood naphtha*, is the substance used in Great Britain for this purpose. In 1855 the Board of Inland Revenue sanctioned the employment in various industries of a mixture of nine parts ethylic alcohol (spirits of wine) and one part methylic alcohol, and they agreed to allow the use of this *methylated spirit* duty free under certain restrictions.]

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* The substances allowed by the law to be used for this purpose [in Germany] are what are called *pyridine bases*. We have already learnt that tar is produced in gas making, besides ammonia which is a compound of nitrogen and hydrogen. The tar contains certain nitrogenous substances which can be defined chemically as derivatives of ammonia, and which, like ammonia, have a very marked odour; some of them indeed have an exceedingly disagreeable odour. Among the products of the distillation of gas-tar, a process we shall have to consider hereafter, are those pyridine bases that are used for mixing with spirit for the purpose already indicated. As their name implies, these substances are capable of uniting with acids to form salts (see p. 51).

[I have put this part of the text in a footnote, and have replaced it by the sentences in a square bracket, because of the differences between the German and the English methods for making spirit undrinkable.—Tr.]

The preparation of pure spirit for making spirituous liquors is not to-day a very difficult undertaking. The shops where these liquors are sold are generally still called distilleries [in Germany]. This name is a survival from the time when the proprietors of the shops themselves carried on the preparation of distilled liquors on a small scale, whereas nowadays the industry is conducted by large manufacturers.

Liqueurs are now made, very conveniently, by diluting the spirit obtained from the large manufacturers till it acquires the proper taste, and then adding sugar, and one or more of those fruit essences which are extracted from various fruits and are sent into the market by the manufacturer. It is possible to prepare such *fruit ethers* by purely chemical methods, without using fruits at all; and those that are prepared in this way are more and more driving out of the market the essences obtained from the fruits themselves.

Many *liqueurs* are made by soaking the flowers of plants, for it is chiefly these that are used, for a long time in spirit, and then drawing off the liquor which has acquired the odour of the flowers and also a peculiar flavour.

Brandy, arrac, and rum are not, however, prepared in this way. They are made by the direct distillation of fermented liquids; and each owes its peculiar flavour to certain substances which volatilise and condense in the process of distillation.* Brandy is distilled from wine; the colour is derived from the vessels of oak wood wherein it is stored. Arrac is made in India, chiefly by distilling fermented rice. The preparation of a spirituous liquor from rice is similar to the process we are accustomed to use in preparing corn spirit. Rum is manufactured in the West Indies from fermented sugar molasses (see p. 77).

As these three liquors are free from sugar, as must be the case from the methods of their preparation, they may be used without harm by patients suffering from diabetes, by whom *liqueurs* must be avoided.

The following analyses show the quantities of the most important ingredients in some of the spirituous liquors commonly consumed.

	Alcohol.	Sugar.
Brandy ...	53·82 per cent. by volume	—
Arrac ...	60·74 ,, ,,	—
Rum ...	77·62 ,, ,,	—
Kümmel ...	33·90 ,, ,,	31·18 per cent.
Benedictin	46·20 ,, ,,	32·57 ,, ,,

Before leaving this part of our subject let us examine the question, which we have hitherto passed over, as to how far alcohol can be said to possess any value as a food. In what has been said hitherto we have followed the example of all the standard authors in regarding this value as non-existent. At the same time we must say that, if starch and sugar are foods because the carbon which they contain is finally burnt in the body to carbonic acid, then alcohol, which is a substance intermediate between sugar (or starch) and the final product of the decomposition of sugar—namely, carbonic acid—will also be wholly burnt, in the long run, in the body. Indeed, as the composition of alcohol is simpler than that of the fats in the body, which fats are eventually burnt in the organism, alcohol ought to be more easily oxidised than these fats, and therefore the use of alcohol should lead to some saving in the consumption of these substances. Nevertheless many experiments have shown that the significance of alcohol as a source of nourishment for people in good health is extremely small.

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* These substances may be called raw spirit with a very agreeable flavour.

On the other hand, experience shows that matters may be very different in cases of illness. It is apparent to every one that the loss of energy which sick people suffer from, who cannot consume the ordinary kinds of food, may often be stopped by the use of wine or champagne which they will take with pleasure. This can only be explained by supposing that, although fats and albuminoids are burnt with difficulty in the bodies of those who are weakened by illness, nevertheless alcohol, which is more easily oxidised than these two substances, can be oxidised even in their weak condition without too much difficulty, and can in this way supply the heat and the vital energy which are required.

LECTURE VI.

Wine vinegar.—Wood vinegar.—Glacial acetic acid.—Wood spirit.—Acetone.—Gunpowder.—Greek fire.—Fulminating mercury.—Guncotton.—Dynamite.—Collodion.—Blasting gelatin.—Cordite.—Wool.—Cotton.—Silk.—Artificial wool [Shoddy].—Carbonising.

We begin to-day with vinegar.

Experience shows that wine and beer, which are alcoholic liquids, become sour when they are exposed to the air for some time. These liquids lose their intoxicating properties, and become so sour that they are undrinkable except when mixed with other substances. The new liquids, however, are used as adjuncts to foods, to which they impart an agreeably sharp flavour.

When an alcoholic liquid becomes sour the alcohol in it is changed to acetic acid, and the liquid thus produced is called *vinegar.*

We have learnt that the juice of grapes very easily changes into wine. The transformation of wine into what is called wine vinegar takes place almost as easily, and for this reason wine vinegar has been known since very early times.

The production of acetic acid from alcohol consists in an oxidation of the latter substance; this addition of oxygen, and therefore the passage from alcohol to acetic acid, is easily carried out in the laboratory. But the change is effected by atmospheric oxygen only in the presence of a certain mould, to which the name *Mycoderma aceti* is given. This mould is found everywhere in the air; it is effective when vinegar is already present.

The preparation of wine vinegar is carried on nowadays in the following manner. Boiling vinegar is poured into oaken barrels so as to soak the wood thoroughly, and the barrels are then filled to about two-thirds with wine. A series of holes is made in the barrels above the level of the liquid inside to insure free access of air to the surface of the liquid. The change is complete after about fourteen days. Half of the liquid is drawn off to be sold as vinegar, and the barrels are filled up with fresh quantities of wine. The process may go on for some years before it is necessary to clean the barrels.

It is necessary for the normal process of acidification that the wine should not contain more than about 10 per cent. of alcohol. Stronger wines must be diluted with water.

Cider, perry, and beer can be manipulated in a similar way. Vinegar made in this way from ordinary beer retains a bitter aftertaste, derived from the hops, which cannot be removed. For this reason it was once customary to prepare a beer without hops, for the special purpose of manufacturing vinegar from it.

As the process of vinegar making consists essentially in the oxidation of alcohol any kind of commercial spirit may be employed for the purpose; and large quantities of vinegar are made to-day from commercial spirits. The spirit must be diluted until it contains not more than 10 per cent. of alcohol; it is then treated in the way already described for making vinegar from wine. The yield of vinegar is, however, much smaller when spirit is used than when wine is employed; for the souring of spirit is as difficult as the souring of wine is easy. For this reason another method has been employed since about 1820 for making vinegar from spirits; this is called the *quick vinegar process.*

A deep wooden vat, provided with a false bottom, is filled up with shavings of beech wood, which experience has shown to be most suitable wood for the purpose. The shavings are thoroughly soaked in vinegar, and dilute spirit is allowed to trickle slowly on to the shavings from the top of the vat. Many holes are bored in the sides of the vat in such a way that air can enter, but liquid cannot escape, through them. The alcoholic liquid is thus spread over a very large surface while it is exposed to the oxidising action of the air. The acidified liquid collects beneath the false bottom; it is drawn off, and passed through the same vat three or four times before the oxidation is completed.

The strongest vinegar that can be obtained by this method contains about 10 per cent. of acetic acid. The following analytical results show the quantities of acetic acid in various vinegars.

Strongest vinegar	10·30	per cent.	acetic acid.
Wine vinegar	5·37	”	”
Ordinary white vinegar ...	4·63	”	”
Ordinary brown vinegar ...	3·53	”	”

Brown vinegar may derive its colour from being prepared from beer brewed without hops or from red wine; but it is more often coloured by a little burnt sugar (see p. 72).

Vinegar essence can be bought to-day containing from 25 to 50 per cent. acetic acid, from which ordinary household vinegar is made by adding water.

This essence cannot of course be made by the method already described, inasmuch as that method is not applicable to liquids containing more than 10 per cent. of alcohol, and therefore producing a corresponding percentage of acetic acid.

The source of this vinegar essence is quite different from that of ordinary vinegar; it is made by the dry distillation of wood. We have already dealt in detail with the dry distillation of coal (see gas making, p. 30), the chief products of which are gas, an aqueous liquid (ammonia water), and tar. Products corresponding with these are obtained by the dry distillation of wood. But gas from wood cannot compete with coal-gas, and is scarcely used, while the watery liquid obtained by the distillation of wood is not basic, like ammonia water, but has acid properties. This liquid contains acetic acid, mixed with a great many other substances which are used in ordinary life, just as the crude acetic acid is used under the name of wood vinegar.

Wood spirit is one of the liquid products of the dry distillation of wood. The chemical composition of this substance is that of the simplest possible alcohol (see p. 113). Like fusel oil, it is undrinkable; it is much used in England for adding to ordinary alcohol to produce methylated spirit (see p. 116). Another product of the dry distillation of wood is a clear, colourless liquid called *acetone*, the chemical composition of which is not so simple as that of wood spirit. This substance is made use of in the production of aniline colours; it is also much used as a solvent, and in this *rôle* we shall meet with it again when we are considering the preparation of smokeless powder.

But it is the acetic acid in the liquid obtained by distilling wood which interests us most at present. The acetic acid in this liquid is coloured brown by the presence of tarry matters. Pure acetic acid, free from water, is obtained from this brown liquid by processes which are too complicated to be considered in detail by us. Pure acetic acid is a clear, colourless liquid, with a very strong odour of vinegar; it has the property of solidifying at a low temperature to a solid very much resembling ice, which solid becomes liquid again at 17° C. [62·6° F.]. Because of this behaviour pure acetic acid is commonly spoken of as *glacial acetic acid*, a name which is quite superfluous and has a flavour of mystery about it. When the acid is diluted with its own weight of water it is known as vinegar essence.

We have now said enough about the relations of foods and condiments to human life; and we shall proceed to consider other subjects which require some chemical knowledge for their elucidation.

We have already made mention of saltpetre in speaking of the use of soda saltpetre as a source of nitrogen to the agriculturist (see p. 52). Potash saltpetre, however, is used for a very different purpose; it is the foundation of all the varieties of gunpowder, a substance which is beginning to be partially supplanted by the smokeless powders introduced about the year 1886.

Potash saltpetre is the salt that is formed by combining the base potash with nitric acid (see p. 52). Now if nitric acid is allowed to react with such an organic substance as *cellulose* (regarding which we shall learn more when we consider the manufacture of paper), a compound is formed by the nitrogroup of the nitric acid entering into the molecule of the cellulose; this nitrogroup consists of an atom of nitrogen combined with two atoms of oxygen. The compound formed in this way is called *nitrocellulose*; this compound, and others similar to it, form the basis of the newer explosives and also of smokeless powder, which have to be dealt with later.

The compound of nitrogen and oxygen which is fixed in gunpowder in the form of saltpetre is also, in the form of the nitrogroup, the explosive ingredient in all modern smokeless powders. Notwithstanding innumerable attempts no better or equally good substitute has been discovered for this compound, and the nitrogroup still reigns supreme in the sphere of explosives.

Neither the Greeks nor the Romans were acquainted with saltpetre, nor with any mixture resembling gunpowder. Saltpetre seems to have come into Europe in the fifth century, from India or China, by way of Constantinople.

The discovery was made in the Arsenal at Constantinople that if combustible substances were mixed with saltpetre these substances could be burnt in such a way that the burning did not cease until the mixture was entirely consumed. We now know that this property of saltpetre is connected with the large quantity of oxygen, 47·5 per cent., which the salt contains. The saltpetre brings oxygen, which we know to be the most important element in processes of combustion, in the solid form, into any mixture of which the saltpetre is an ingredient.

It was soon found that the most suitable mixture for burning was one made of saltpetre, charcoal, and sulphur. This mixture was known as *Greek fire*, and by its use Constantinople was able to defend herself for a long time from all her enemies. The Arabian fleet was burnt by the use of this substance in the seventh century, and at last the Arabs abandoned the attempt to conquer the city. Western Europe, which did not possess this means of defence, could not resist the Arabs, who crossed into Spain in 711, and for many centuries ruled that country. In the tenth century Constantinople used Greek fire to drive back an inroad made by Bulgarians. This substance, Greek fire, has evidently played an important part in the development of the nations, and the discovery of the modification of Greek fire which we call gunpowder has increased this influence. It is a noteworthy fact that, although all those peoples who fought against Constantinople tried to discover the secret of making Greek fire, nevertheless the secret was kept for five or six hundred years. Such a fact seems to us to be almost inexplicable. We cannot understand how a discovery of so much importance should have been made so long ago, nor how the city that was in possession of this secret should have been able to keep it almost up to our time.

The earliest writings that give an account of the composition of Greek fire are those of the Byzantine author Marcus Græcus, who lived about the year 1200. A Latin translation of a book by this author has come down to us; its title is *Liber Ignium ad Comburendos Hostes (Book of Fires for destroying the Enemies)*. It does not appear from this book that Marcus Græcus was the first to publish to the world the secret of making Greek fire; it rather seems as if the knowledge of the manufacture had already spread by word of mouth, and that Constantinople could no longer claim the monopoly of the process.

The book of Marcus Græcus always speaks of Greek fire as merely a very combustible mixture, although the composition of the mixture described in the book is not very different from the compositions of the gunpowders that are used to-day for military purposes. The following figures show this.

		Greek fire, according to Marcus Græcus.	Prussian military gunpowder.
Sulphur	...	11 per cent.	10 per cent.
Carbon ...	...	22 ,,	16 ,,
Saltpetre	...	67 ,,	74 ,,

There is now no chance of finding out when and by what means the discovery was made that a most energetic explosive power was hidden in this mixture—an explosive power which was indeed greater than that of any other artificially produced substance then known. This discovery, which must have been made after the time of Marcus Græcus, was soon turned to account for the purposes of war; the first metal cannons were cast at Florence in 1326, and soon after this we find enumerations of the pieces of artillery brought into action in the battles and sieges of the period. But the explosive was not used in hand weapons until a much later period. About the year 1500 soldiers who used guns stood in files thirty-seven deep; the reloading of the weapons occupied so much time that when a man had fired he passed to the rear, and he was not ready to fire again until the thirty-six men in front of him had discharged their weapons. This state of affairs lasted till the time of Frederick the Great, when such great improvements were made in flintlock guns that, since then, the gain or loss of battles has depended very largely on the fire of the infantry.

Many attempts to improve gunpowder have of course been made from time to time; but the figures already given show that the changes made in its composition have not been very marked. In former times the preparation of gunpowder was a very simple operation; the three ingredients were mixed and the thing was done. Great advances have been made in this, the purely technical, part of the manufacture. The method of mixing the powder that is made in the largest quantities has been carried to very great perfection, and at the same time the most suitable size of grains has been found out long ago. Powder which is to be used in large cannons, for instance, is pressed into the form of six-sided prism-shaped pieces of the size shown in the figure (fig. 15). The pieces of this prismatic powder are pierced with holes, which insure the simultaneous burning of the grains from within and from without. Nevertheless this powder burns much more slowly than that made in fine grains. Hence the force of the explosion in a tube takes effect more slowly when large grained powder is used, and for this reason powder of this kind is more effective in the modern very large cannons. We have mentioned only one of the advances, based on logical reasoning, that have been made in the preparation of the most useful kind of powder, to make clear that, although gunpowder reminds us of Greek fire so far as its composition is concerned, yet the Greek fire, that was thrown like a burning torch at the enemy, was merely a plaything compared with the modern powder.

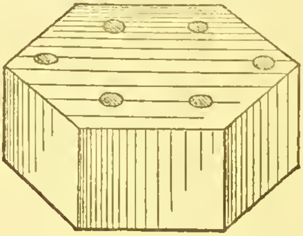

Fig. 15.

The following figures show what can be done with prismatic gunpowder. A cannon exhibited by Krupp at the Chicago Exhibition, when charged with 115 kilos. [253 lbs.] of this powder, propelled a shot weighing 215 kilos. [473 lbs.] to a distance of 20,226 metres [12½ miles]; the flight of the shot occupied 70 seconds, and the highest point attained was 6,540 metres [4 miles] above the earth, while the height of Chimborazo is only 6,421 metres [3·99 miles]. Six such cannons have been made for the protection of the new Elbe-Baltic canal.

The great advances made in chemistry in this century have led to a complete revolution in regard to gunpowder. Very explosive substances have long been known in the laboratory, but the extraordinary violence of their action made it impossible to use them in guns, because they would burst the gun before they could set the shot in motion. Only one compound found an application in connection with guns, and that was *fulminating mercury*, a substance which explodes when struck sharply. It was used in percussion caps for starting the explosion of the powder in the gun, in place of the flintlock which had succeeded the untrustworthy and unsafe tinder. In the flintlock the igniting spark was produced by the fall of a piece of steel on flint.

When gunpowder explodes a great deal of smoke is produced. The smoke is derived from the potassium which is contained in the nitre of the powder. This very stable metallic substance is changed during the explosion into sulphate of potash and other similar compounds ; these substances are solids, and they are broken up by the explosion into a very fine dust that floats in the air for a long time and forms the smoke of the powder. Matters are quite different when a little guncotton is ignited—and we must now proceed to consider this substance ; the guncotton burns instantaneously and without a trace of smoke.

Why then should there be this great difference between the old and the new explosive substance ? Cotton wool consists of *cellulose*, a compound of six atoms of carbon, ten atoms of hydrogen, and five atoms of oxygen ; it has therefore the same composition as starch (see p. 72) ; it is a carbohydrate. When cotton wool is treated with nitric acid, the action of which is increased by the addition of sulphuric acid—the mixture of these acids is technically known as "*nitroacid*"—nitrogroups enter into the cellulose molecule, as has been mentioned already. While the old powder was a mixture of substances prepared as carefully as possible, the new explosive substance is itself a chemical compound. The old powder burnt away; when the new substance is used as an explosive there ensues an instantaneous falling to pieces of the molecule. While a kilogram ($2\frac{1}{5}$ lbs.) of powder requires about the hundredth part of a second for its combustion, about one-fifty-thousandth part of a second suffices for the decomposition of a kilogram of guncotton.

When guncotton is burnt carbonic acid is produced from the carbon and water from the hydrogen, and the necessary oxygen comes partly from the cotton wool, but more particularly from the nitrogroups—for several nitrogroups enter into the molecule of cellulose when guncotton is made. The nitrogen of the nitrogroups is given off as nitrogen. As we have seen, the explosion of this material produces gaseous substances only, for the water that is formed is gaseous at the high temperature whereat the burning is completed. As these gases are colourless they are of course invisible; guncotton therefore burns without any smoke.

Guncotton was the first of the more recently discovered explosives that was found to be practically useful; and soon after its preparation, which was towards the end of 1840, many countries laid in great stocks of this substance. But the stores of guncotton sometimes exploded suddenly without any apparent reason, and caused enormous damage. All confidence in the material was lost; but after about thirty years' labour such definite knowledge has been obtained regarding the conditions of preparation of a stable substance that guncotton can now be handled without danger. It was also discovered after a long time—and this fact has proved very important—that wet guncotton is as convenient as the dry material, or even more convenient, for explosive purposes. And nowadays torpedoes charged with rolls of moist guncotton which have been subjected to enormous pressures are possessed of such great destroying power that even the best defended vessels cannot withstand the impact of these weapons.

The charging of these torpedoes is perfectly safe, inasmuch as moist guncotton obstinately refuses to ignite when brought into contact with an ordinary flame. Explosion takes place only after burning has been started; and this fact is the essential part of the most important discovery just mentioned.

To say that explosion occurs only after burning has been started means that the guncotton must receive a shock which in the physical sense is extremely sharp. Such a shock is produced by the explosion of fulminating mercury, for instance. If a detonator of this material is exploded in a mass of moist guncotton the explosive wave causes a disruption of the atoms which are arranged in a definite way in the molecule of the guncotton—or *nitrocellulose*, as this substance is called in chemistry—resulting in the falling to pieces of the molecule, and hence in the explosion of the guncotton whether that be wet or dry.

Long before it had become possible to handle guncotton with perfect safety another of the modern explosives had come into favour for the peaceful purposes of mining, etc. ; this was *dynamite*, a substance the name of which is now heard everywhere in the world.

We have already got to know something of glycerin as a constituent of fat (p. 21). When glycerin is mixed with "nitroacid" (see p. 130) three nitrogroups are taken up by the glycerin ; the product is therefore very rich in this most powerful constituent. The *nitroglycerin* produced in this way is a liquid, like the material from which it is made, and it is not very suitable for use as an explosive. It is therefore mixed with a sufficient quantity of very fine sand, called *infusorial earth* (*Kieselguhr*), to produce a solid mass, and this solid is known as dynamite, a substance that has been employed in blasting the St. Gotthard tunnel, and in many other works of a like character.

Meanwhile quantitative deductions from the theory of projectiles had shown that much more efficient results would be obtained by decreasing the diameter of the projectiles to be used in cannons, provided that a greater impulse than was possible by the employment of gunpowder could be given to the shots. Thereupon began the search after new kinds of military powders—which should necessarily be smokeless, for reasons we can now understand—on the lines suggested by the properties of the nitrocompounds. The discovery by the French of *melinite*, a substance that was much talked about a few years ago, was one of the results of this search. Melinite was prepared by the action of "nitroacid" on *carbolic acid*, a substance much used as a disinfectant. The result of this action is to introduce three nitrogroups into the carbolic acid, and so to form *picric acid*, which is a compound that, like guncotton, can be exploded when moist by an initial detonation. The methods of preparation of this powder are kept as a state secret; but the substance has not stood the test of time. Guncotton seems to have come out victorious in all contests with this competitor, as with the other competitors in the domain of modern smokeless powders. At any rate guncotton appears to be a constituent of all these powders, as far as one can find out considering that the methods of manufacture of smokeless powders are kept secret by the different states.

What makes guncotton so very suitable is its property of dissolving in various solvents and so producing a liquid that is eminently adapted for making powders. For instance, the well known substance *collodion* is a solution of guncotton in a mixture of ether and alcohol. If this solution is evaporated a film remains, which can be obtained of any desired thickness; by cutting this film into small pieces a smokeless powder is produced. The technical preparation is not so easy as this, but still it is carried out on these lines.

As guncotton alone would be too violently explosive for use in guns it is customary to add some indifferent substance—camphor, for instance, was used for a long time—to a solution of guncotton, and then to evaporate the solution; in this way a solid is obtained, which may be regarded as diluted guncotton, and which can be used as a smokeless powder. It is evident that a powder of any desired strength, and suitable for various purposes, can be obtained by this method of procedure.

The most powerful of all explosives is made by saturating guncotton with nitroglycerin ; this explosive is used in mining operations, but it cannot be employed in guns. Guncotton does not dissolve in nitroglycerin, but it swells up and forms a jelly-like substance which is known as *blasting gelatin*. This blasting gelatin is the most energetic explosive we have at our disposal; the strength of it can be modified by using more or less guncotton ; and it seems, from what has been said already, that this explosive cannot be surpassed, for the energy of nitroglycerin is not lessened by the addition of such a substance as sand, as is the case in making dynamite, but is rather increased by the guncotton that is employed in the manufacture.

If the nitroglycerin is diluted with acetone (see p. 124) before the guncotton is added, and indifferent substances are then added for the purpose of diminishing the explosive force of the powder that is to be prepared, and if the greater part of the acetone is then removed by evaporation, the substance that remains can be made into long threads of any desired thickness by the help of machines. *Cordite* is prepared by evaporating the rest of the acetone from these threads ; this smokeless powder (the name of which is derived from the word *cord*) is used in the English army. The explosive force of cordite can be modified by adding greater or smaller quantities of indifferent substances to the solution from which it is obtained.

Many attempts have naturally been made to prepare suitable powders or explosives by methods quite different from those that have been described. It is certain, however, that practical results, especially as regards the freedom of the product from danger, are to be obtained only by the use of compounds containing nitrogroups.

If, for example, the nitrogen atom in saltpetre is replaced by an atom of chlorine the new compound *chlorate of potash* is obtained. Thus

KNO_3	$KClO_3$
Nitrate of potash.	Chlorate of potash.

The abbreviation for nitrogen is N, the first letter of the name; the abbreviation Cl is used for chlorine, that is the first and third letters of the name. The formulæ which are written with the help of these contractions show very clearly the chemical similarities of the two compounds we are speaking of.

Chlorate of potash may be mixed with sulphur or carbon, or with both of these substances. These mixtures are extremely powerful powders, as would be expected; but they cannot be handled with safety, for a blow, or even a great pressure such as can scarcely be avoided in the manufacture on the large scale, causes them to explode. Hence they cannot be made in factories; indeed their preparation in the laboratory is dangerous. Superficially mixed preparations of chlorate of potash and similar compounds with other substances are employed in making fireworks; these mixtures are poured into covers, generally of a cylindrical shape, in which they are gradually burned.

We must now speak of the substances used for clothing. Substances made from both animal and vegetable fibres are used for this purpose, and leather is also employed.

Fibres of animal origin are very different chemically from the fibres of vegetable substances, inasmuch as the former contain nitrogen, but the latter do not contain this element. If animal fibres catch fire they produce badly smelling nitrogenous substances—they are said to smell like burning horn; vegetable fibres, on the other hand, produce a smell like that of burning paper.

We have naturally but little to say here about the fibres themselves. The most important things made from animal fibres are wool and silk. Wool has a very rough surface set with many little projections. Woollen cloth is made by stretching woollen threads on a frame, and so forming the warp, on which the woof is spun by a shuttle which flies too and fro; the cloth made in this way is very similar in appearance to stuff made of strong linen fibres. But if the material is now wetted and worked vigorously, or *milled* as the expression is, the projections of the single threads are kneaded into one another—the cloth is said to be *felted* or *fulled*—and the product has the surface we are accustomed to perceive on woollen goods. The processes to which the cloth is then subjected—*shearing*, *teasling*, etc.—belong to the technical details of the manufacture, and do not interest us here.

The properties of silk do not allow of its being felted; the single threads can therefore be distinguished in finished silken fabrics. This is the case also with linen and cotton. However much cotton or linen goods may be washed, the single threads always remain side by side, and they can be separated by picking.

But artificial wool is much more interesting to the chemist than the materials that are spun from the natural wool.

When woollen clothes have become unfit for further use because of constant wear the greater part of the wool that was used in making them still remains in the clothes; only their appearance is bad—they have gone into holes, etc.

It is easy to see that if woven goods, such as hosiery, are completely picked to pieces—and this can be done without trouble by a machine—a wool will be obtained which may again be spun, and which, although not equal to unused wool, will yet be of some service.

Now it is not only such woollen goods that are picked to pieces, but cast off wearing apparel, that can be obtained in much greater quantity, is also treated in this way. All the stitches must be taken out of the clothes before they are picked to pieces by the machines. This preliminary treatment is done by workwomen. The odd pieces of cloth thus obtained are sorted, and then pulled to pieces. The wool is thus got out of the cloth; but a little consideration will show that the threads of this wool will be much shorter than those of the wool from which the cloth was originally manufactured. Nevertheless this wool is an excellent material for weaving, and it finds a very suitable use in making up those cheap stuffs which are purchased by people that are not well to do.

The manufacture of such stuffs would be very easy were it not for the following consideration. Cotton is much cheaper than wool; hence some cotton is generally mixed with wool before spinning, in order to reduce the price of the articles manufactured therefrom. But as wool and cotton cannot be dyed equally (the reason of this we shall learn later) it is not customary to mix cotton with wool in a casual manner; the practice rather is to make the warp of cotton threads and the woof of wool. When the cloth is milled the wool is mingled with the cotton sufficiently to cover and so to hide the latter.

It is only at those parts of the clothes where there is much wear—at the armholes, for instance—that the wool soon gets rubbed off and the tightly twisted separated threads of cotton make their appearance. If such clothes are again picked to pieces to make artificial wool—known as *shoddy* or *mungo*—the stuff contains cotton, and when the process has been repeated several times the material becomes quite useless. The greatest difficulty in the way of using such stuffs over again is that wool and cotton cannot be dyed equally in the same dyeing bath.

To make shoddy that contains cotton fit for use the cotton is removed by a process known as "*carbonising*." The stuff is placed in dilute sulphuric acid, or in some other liquid which acts in a similar way. The liquid used attacks the cotton in the material in such a way that after drying at 120° to 125° C. [250° to 260° F.] the cotton is disintegrated to a powder, while the wool is practically unaffected. The cotton can then be completely removed by working up the material in machines.

Most of the fibres that are spun into materials are colourless as they occur naturally. But as it would not always be convenient to wear white garments the practice of dyeing materials has prevailed since early times.

LECTURE VII.

Tanning.—Leather.—Removing hair from hides and softening them.—Tanning materials.—Barks.—Quebracho bark.—Sumac.—Tanning extracts.—Sole leather.—Alum tanning.—Glove leather.—Furriery.—Iron and chrome leather.—Chamois leather.—Wash leather.—Parchment.—Bleaching on meadows.—Blueing washed linen.—Bleaching by chlorine.—Bleaching powder.—Antichlors.—*Eau de Javelle.*—Sulphurous acid.—Peroxide of hydrogen.—Dyeing—Mordants.—Lakes.—Substantive colours.—Coal tar colours.—Indigo.— Alizarin.—Colouring pastes.—Colouring extracts from woods.—Logwood.—Calico printing.

BEFORE dealing with the subject of dyeing it is advisable to say something about the preparation of leather, which, being the substance that serves as a covering for our feet, naturally finds a place after those materials that are woven from threads. For many other purposes of ordinary life also nothing can be substituted for leather.

Leather is the skin of animals made strong and durable. The process of making the skins durable, and at the same time also permanently pliable, is called *tanning.*

Fresh skins of animals are extremely liable to undergo putrefaction. They lose this tendency when they are dried ; but the dry skins are hard and brittle because their fibres are glued together. In the process of tanning the tanning material is brought between the fibres, and so prevents the adherence of those fibres to one another; leather is thus produced the pliability of which is more or less like that of the skins of living animals.

The first thing to be done with skins that are to be used for making leather is to remove the hair from them. The oldest method for doing this is known as "*sweating*"; this method is still used to some extent in an improved form to-day. The process consists in leaving the moistened skins or hides for some time by themselves; a slight putrefaction occurs which so softens the hair that it can be scraped off without much trouble. The sweating is stopped as soon as the hair is softened sufficiently. The process of loosening the hair can also be easily accomplished by the aid of chemicals; and burnt lime has long been used for this purpose. The lime is slaked with a large quantity of water (we shall have to deal with the slaking of lime when we come to speak of mortar), and the hides are steeped in the *milk of lime* thus obtained. A compound of sulphur and lime, or the chemically similar compound *sulphide of soda*, is a more effective depilatory than lime. These substances are now manufactured especially for the purpose of removing the hair from hides that are to be made into leather.

After the hair has been removed the hides are soaked in some liquid which takes away any lime that still adheres to them, because if this lime were allowed to remain in the hides it would interfere with the tanning processes. Very dilute acid—sulphuric acid, for instance—may be used for this purpose; when soaked in such a bath the hides swell up to twice their original thickness, and they so become more easily permeated by the tanning materials.

It is, however, customary to employ a method that has been handed down from ancient times, and which is purely empirical. The acid bath is prepared by the process of lactic fermentation, with which we are already familiar ; the result is found to be more satisfactory than when the bath is made of any one of the dilute acids that have been tried for this purpose. The bath is prepared by steeping wheat bran in water, adding sour dough, and allowing the lactic fermentation to complete itself at about 50° C. [120° F.]. As we already know, small quantities of other acids besides lactic acid—butyric acid, for instance—are produced by this process (see p. 87).

When the hides are steeped in this bath, after the liquor has become cold, they swell up and become ready to absorb the tanning substances from the materials used in the next stage of the process.

Tanning substances—that is to say, substances which convert the skins of animals into leather—are found in very many plants. One speaks, for example, of the *tannin* of tea and coffee. The high price of such plants as those that produce tea or coffee of course negatives the employment of these materials in leather making. Barks are the most commonly used materials, and especially the bark of the oak, which, when cut into small pieces, is known as *oak tan*, or simply *tan*. The trees are barked when they are from fifteen to twenty years old, as the proportion of bark to wood is greatest at that period of their growth.

To prevent the unnecessary withdrawal of energy from the soil—which means, as we now know, the uncalled for removal of inorganic salts—the wood of the trees is burnt on the spot, and the ashes go to enrich the soil. Of course the soil may also be enriched by the use of artificial manures.

The barks of firs, pines, and in many places also the bark of the walnut tree, are employed for tanning, besides oak bark; but these are generally mixed with oak bark before use. In consequence of the large quantities of leather that are used nowadays substitutes for bark are derived from other sources, especially from certain foreign trees and shrubs, for the tanning substances are found in other parts of plants besides the bark. The only one of these woods we shall mention is *quebracho wood*, about which there has been of late much talk [in Germany] because of the proposal to put an import duty on this wood in the interests of the possessors of forests the trees of which are used for tanning.

Quebracho wood is a very hard, dark red wood, which is exported in large quantities from Argentina; after it has been rasped to pieces by a machine it is used in the same way as oak bark.

Sumac is also much used. It is a powder made by rubbing the young dried shoots of plants of the *Rhus* order which grow in the southern parts of Europe. But we need not make any further enumeration of the materials used in tanning.

Tanning with oak bark, or a substitute for bark, is conducted by placing the swollen hides and the tanning material in alternate layers in a pit until the pit is full, and then running in water sufficient to cover the whole of the contents. The tanning substances gradually pass into solution, and they are slowly absorbed by the hides. As thick hides require very large quantities of tanning material they must be mixed repeatedly with fresh layers of tan; the process therefore occupies a long time, even as much as two years or more; but for that reason the product is excellent.

Naturally attempts have been made to shorten the process; and it has been found possible to complete the making of leather in about three months by extracting the tanning material with water and then steeping the hides in the liquor thus obtained.

This brings us to the consideration of extracts used in tanning. Such extracts have been sent on to the market for many years from the East Indies, where they are prepared by extracting suitable woods or leaves with water, and then evaporating as far as possible so as to decrease the cost of transport; the most important of these extracts are known as *gambier* and *catechu*. Similar extracts have been prepared in Europe since about 1880, and the cost of carriage of tanning materials has thereby been much diminished; extract of oak bark, for instance, comes from Hungary, and extract of quebracho wood is made in the seaport towns to which the wood is brought from Argentina. The manufacture is carried on by rasping or grinding the material, exhausting with water, and evaporating the aqueous solution thus obtained. The evaporation is not effected in open vessels, but under greatly reduced pressure in a way like that followed in making sugar, about which we have already learnt something (see p. 76). This method preserves all the desirable properties of the extracts, which could not be done were the evaporation conducted in the ordinary manner.

The preparation of leather by the use of such extracts is a much less troublesome process than the manufacture by the older methods; and the process is also quickened to an extent that is quite astonishing.

A German patent, registered in 1892, asserts that the thickest sole leather can be made in thirty-six hours, by treating soaked hides with an extract liquor eight times more concentrated than that generally employed, in a machine which revolves about ten times per minute. Instead of requiring a couple of years, as was formerly the case, prepared hides can now be made into leather in less than two days; and this patent is not impracticable, as many patents are, for sole leather made by this method—and it is only for sole leather that the process seems to be suitable—has taken a firm place on the market.

Besides the methods of tanning that we have been speaking of there are two other processes that are much used; these are *alum tanning* and *chamois leather tanning.*

Chemically considered, alum is a double compound of sulphate of potash and sulphate of alumina. When soaked and cleaned hides are brought into a solution of alum to which common salt has been added, the alumina acts in the same way as the tanning substances do which we have already considered; the alumina penetrates the hides and by its deposition between the fibres prevents the hardening of the material which is subjected to this tanning operation. When this product is thoroughly rubbed and worked with fat the fat is taken into the substance, and the material thus obtained is the most tenacious kind of leather that is known.

The leather for kid gloves is made in this way, working with very great care to prevent the formation of spots, etc., and using the skin of young animals, especially those of kids and lambs. The tanning liquor used for this purpose consists of a solution of alum to which egg yolks and meal have been added. Egg yolk consists chiefly of albumen and fat, the latter being present in an extremely finely divided state; and it is to the thorough permeation of the skins by this finely divided fat, along with the tanning material, that the remarkable pliability of kid glove leather is due.

Although alum or white tanning is not nearly so effectual as tanning by oak bark, nevertheless there are many purposes for which the latter cannot be used. The leathers made by these two methods show great differences in their behaviour towards water. Experience in the wearing of boots shows us that good sole leather is impervious to water; but the tanning matter is nearly all withdrawn from white tanned leather by the action of a large quantity of water. We know, for instance, that when gloves get very wet they shrivel, and behave like untanned skins.

Alum is also employed in the tanning of skins to be used as furs. The details of the various processes differ much, but the method is essentially a tannage by fat and alum. Speaking generally, the skins are thoroughly cleaned with soap, then dried, and then fat is rubbed on to their inner sides and worked in as thoroughly as possible and as long as any of it is absorbed; the skins are then placed in a sour bran-drench, which causes a slight swelling after about twenty-four hours; the bran is then removed, and the tanning is effected by a solution of alum and common salt.

Alumina is a base (see p. 51); hence it does not seem absurd to suppose that other bases might be substituted for alumina in tanning, and that new kinds of leather might thus be produced. A consideration of the properties of various bases by experts led to the conclusion that there are only two which would be worth trying, and these are oxide of iron and oxide of chromium; and as a fact leather has been prepared by using these bases.

The large factories which were erected in Europe about the end of 1870 for making leather by the use of these materials have not, however, turned out serviceable products, and all of them were soon closed. It would seem, however, from a patent that appeared in December 1895 that chrome leather is still manufactured in America.

We have still to speak of *chamois* or *oil tanning*. Here also the skins are freed from hair, and are swollen; they are then rubbed with fat, fish oil or whale oil being the form of fat that is used, and afterwards they are thoroughly fulled, and are again rubbed with oil as long as any is absorbed. The absorption of the oil is not altogether a mechanical process; a chemical change also occurs, and this is accompanied by the production of a definite smell which indicates that the operation is completed. The skins are then allowed to remain for some time in heaps where they become warm owing to the heat produced by the chemical changes that continue to occur; the rise of temperature favours the chemical reactions, which proceed more rapidly until at last the skins acquire a yellow colour. The result of this treatment is that the fibres become so enveloped in fatty matter that they no longer adhere together—a true leather is produced—and the combination of the fibres with the fat is so intimate that even hot water is not able to dissolve it; for this reason the leather is called *wash leather.* The leather is then washed with potash solution to remove the surplus fat that remained chemically uncombined when the yellowing of the skins began. This fat forms an emulsion with the potash, and is removed by washing with water. If the potash in the emulsified liquor is neutralised with acid the fat rises to the top of the liquor. This fat is found, by experience, to be very suitable for rubbing into leather prepared by the methods of tanning described in the earlier part of this lecture; it comes into commerce under the name of *degras.*

Furs are also sometimes prepared by the methods used in making chamois leather.

Parchment should be mentioned here. Parchment is not a leather, although it is often supposed to be such; it is prepared by removing the hair from the skins of very young animals by means of lime, then cleaning the skins thoroughly and drying them while they are stretched tightly. To give the dried skins a smooth surface they are sprinkled with chalk and rubbed with pumice stone. The product is too smooth for writing on, and therefore, if it is not to be used for binding books, making drums, or some such purpose, it is brushed over with thin white oil paint so as to produce a surface that can be written upon.

We must now return to textile fabrics that we may consider the bleaching and dyeing of these materials. In connection with dyeing we shall have something to say about painting. White, or nearly white, is the natural colour of the materials that are woven into linen, cotton, and woollen goods, and the like.

It would not be altogether pleasant to wear white clothes, because their appearance soon becomes disagreeable; besides this, coloured stuffs confer a more beautiful and more distinguished appearance, as was recognised in the olden days when a purple mantle was worn only by the chief men.

Most of the natural materials that are woven have a shade of yellow in them, and the object of bleaching these materials in the sunshine is to remove this colour. This yellowish coloration is removed, as most colours are, by exposure to sunshine; the process whereby the yellow is changed into pure white is hastened by blueing the goods—this is practised with the household washed linen, for instance. Yellow and blue are complementary colours, and they neutralise one another.

When, in course of time, the making of linen and cotton fabrics passed from the hands of individual home-workers, and the manufactures became concentrated in factories, it was necessary to provide very large bleaching grounds for the goods, and this involved much trouble and expense. In some districts, indeed, where the manufacture of these goods has advanced very much, it would be quite impossible to provide sufficiently large bleaching grounds. Nowadays, and indeed since the discovery of artificial bleaching stuffs, all linen and cotton fabrics are bleaching in the factories, by the use of chloride of lime.

Chlorine is a gas which shows a very marked readiness to combine with other bodies. It was some time after its discovery, in the last quarter of the eighteenth century, before this substance was recognised to be, what we now know it is, an elementary body. Because of its very great activity—an activity greater even than that of oxygen, which up till that time was the most active substance known—the gas was supposed to be a new variety of oxygen, and the French chemists of that period often spoke of *nouvel oxygène.* In consequence of its energetic action on the most different kinds of substances, chlorine destroys the greater number of colouring substances.

The employment of gaseous substances in factory industries is very inconvenient; for this reason chlorine is not itself used as a bleacher, but the compound is employed which chlorine forms with lime when it is passed over that substance. This compound, which was first prepared in 1799, is known as *chloride of lime* [or as *bleaching powder*].

The bleaching action, or, to use a more accurate expression, the chemical energy, of this substance destroys the yellowish tint of white linen or cotton goods in a very short time, and as effectually as the process of bleaching on meadows. But the energy of the bleaching powder is not exhausted by this process; having destroyed the colour, the bleaching powder attacks the fibres of the goods—and it is for this reason that the use of bleaching powder has never found favour with housewives. In factories, however, matters are managed differently; as soon as the goods are bleached the excess of chlorine is rendered inactive by addition of an *antichlor*, and the fibres of the goods are not injured in the slightest. If housewives would but use antichlors they would have no reason for rejecting this most convenient method of bleaching, after they had gained some experience of it.

Many and very different chemical substances may be employed as antichlors; the most commonly used is *hyposulphite of soda.* This salt has no action on washed linen, and as soon as it comes into contact with chloride of lime it forms new compounds which are also without action on the linen, and at the same time the chloride of lime is converted into the perfectly harmless chloride of calcium.

How frequently does the wash smell of chlorine when it is sent home by the washerwoman! Towels treated in this way soon wear out, as their fibres are gradually rotted away; and all this might so easily be prevented by the use of a small quantity of an antichlor.

As chloride of lime destroys colours, so it also gets rid of all kinds of infectious matters, and hence this substance is used, as will be described in a moment, for disinfecting sick-rooms. If some chloride of lime is placed in a plate in the sick-room, and hydrochloric acid is poured over the powder, the chlorine of the chloride of lime is given off as a gas which soon fills the room, and so accomplishes complete disinfection. Although this method of disinfection is very effective, and for that reason is sometimes to be recommended, nevertheless it cannot be employed without danger. At any rate as soon as the hydrochloric acid has been poured on to the chloride of lime every one should at once leave the room. The chlorine gas that is given off has a suffocating smell, and if any quantity of it gets into the lungs it produces spitting of blood. Moreover the smell of this gas will hang about the room for months, even if fresh air is often let into the apartment. For these reasons it is more advisable to make use of other kinds of disinfectants (see Lecture XII.).

In addition to chloride of lime, the substance known as *eau de Javelle* is used commercially as a bleaching agent. The difference between these two substances is that the eau de Javelle contains soda in place of lime; the chemical action of the one is practically the same as that of the other. If eau de Javelle is used—and it is in favour for removing stains, which it gradually destroys—a small quantity of an antichlor—a little hyposulphite of soda dissolved in water, for instance—should be put on the cloth after the cleaning has been effected, as if this is not done the fibres will be rotted.

Chloride of lime cannot be employed for bleaching fabrics woven from animal fibres, because it does not thoroughly bleach such fabrics, but only turns them yellow. *Sulphurous acid*, which is a less energetic bleaching agent than chloride of lime, is employed for taking away the colour from animal fabrics.

Sulphurous acid is the sharply smelling gas that is formed when sulphur is burnt. As the gas is very soluble in water the usual method of working is to hang the goods, after wetting them, in a chamber wherein sulphur is burnt. No special means of destroying the excess of sulphurous acid is required, because, when this method is adopted, only a very little sulphurous acid ever gets into each piece of goods.

There is still a bleaching medium to be mentioned which is often named nowadays, but which has not been able to supersede the older bleachers, notwithstanding great efforts, because it is not possessed of any especial advantage. This substance is *peroxide of hydrogen.*

We have repeatedly said that water is a compound of hydrogen and oxygen, and that it can be represented by the formula H_2O (see p. 67). Now it is possible under certain conditions to add another atom of oxygen to water, and thus to produce peroxide of hydrogen, H_2O_2.

This substance can be used as a bleaching agent in many cases where chloride of lime and sulphurous acid are ineffectual; it is employed especially for bleaching hair, feathers, and ivory. As peroxide of hydrogen can now be manufactured very cheaply, by a process discovered about three years ago, it is possible that the efficiency of this substance may gradually be increased.

We have now to consider the dyeing of textile fabrics. This part of the subject falls into two main divisions: the uniform dyeing of the whole of a piece of goods, and calico printing.

The simplest way of dyeing uniformly a piece of cloth would be to mix the colour with glue in water and to smear this over the goods; but the colour would be very loosely retained, and the cloth would have to be kept from getting wet. Cloth treated in this way would rather be described as coloured than as dyed: the colour is retained better if it is mixed with albumen, and then spread over the cloth, and if the cloth is then heated; the albumen is coagulated and is thus rendered insoluble in water. Although the colour is fairly well held by the cloth still much of it is removed when the cloth is rubbed vigorously.

This process, which is not a dyeing process in the proper meaning of the term, plays a certain part in calico printing. It is applicable only when a solution of the colouring matter acts upon the fibres of the material. There are great differences in this respect; animal fibres, such as wool and silk, behave towards dye-stuffs very differently from vegetable fibres, of which cotton is the most important.

If a dye-stuff, say *fuchsin*, is dissolved in water, and a piece of wool or a piece of silk is drawn through this solution, the colouring matter slowly passes from the solution into the fibres, which it colours red.* But if we place cotton in the same solution we find that the vegetable fibres have not the property of retaining the colouring substance. For if we now wash the red coloured wool or silk with much water the colour is still retained by the material; but when the cotton is treated in the same way it returns to its original whiteness.

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* The fibres play here somewhat the same part as we found was taken by animal charcoal (see p. 45). In the same way as animal charcoal withdraws the colouring substances from liquids —from red wine, for instance—animal fibres are able to combine with colouring matters and to retain these firmly.

All dye-stuffs cannot, however, be applied to wool and silk so easily as this. In wool and silk dyeing it is generally necessary to make use of the method which was the only practicable method for dyeing cottons till the year 1884; it is necessary to use *mordants*. What mordants are will be best understood by the following considerations.

If a solution containing iron is added to a solution of yellow prussiate of potash the beautiful blue substance known as *Prussian blue* is precipitated. Now the best way of dyeing a cloth with Prussian blue is to dip the cloth first into one of the two solutions and then into the other. If the cloth has been soaked in the iron solution before it is immersed in the solution of yellow prussiate, then the blue precipitate is formed in the fibres of the cloth, that is to say, the colouring matter is deposited in the interior of the cloth, and as the precipitate is quite insoluble in water it is not removed by washing even with much water, and hence the cloth is not decolourised. The fabric is really dyed by this process.

The use of mordants is based on such a process as that which has just been described. The stuff to be dyed is first dipped into a liquid called the mordant, which introduces into the fibres of the cloth a substance that reacts with the special dye-stuff to be used and produces a compound which is insoluble in the mordant.

Alumina is very much used as a mordant. In dealing with tanning (see p. 145) we found that alumina is able to enter into combination with animal fibres; in a similar way this substance shows a tendency to combine with both animal and vegetable textile fabrics when these are passed through a properly prepared solution of it.

Alum, which is a double compound of sulphate of alumina and sulphate of potash (see p. 145), was formerly a very important substance in dyeing, inasmuch as it was the only soluble salt of alumina that was also easily procurable. This compound has been prepared since ancient times by an easy process from a kind of earth which is found in certain parts of Europe. As the sulphate of potash in alum is useless for the purposes for which the alum is to be employed in dyeing, chemistry has long ago replaced this double salt by all sorts of other soluble compounds of alumina.

Now if cotton, for instance, is mordanted by being dipped into an alumina solution, and if it is then passed through a solution of fuchsin, the fabric is dyed a fast red; for the fuchsin is deposited in the fibres of the fabric in the form of an insoluble compound with the alumina, and the process is quite similar to what occurred when we dyed with Prussian blue.

The name *lakes* is given to the compounds that mordants form with dyes. Of course we can produce a lake without using fibres: for instance, if we pour a solution of fuchsin into a solution of alumina a red precipitate is obtained; and if we dry this lake and then rub it up with varnish (see forward, p. 169) we have a colour ready for painting wherewith we can cover surfaces in any way we desire.

Alumina is a base, and there are many other bases that may be used in dyeing in the same way as alumina is used. For matters are different here from what we found to hold good in leather making, where alumina was the only practically useful base (see p. 147). It is not only the bases that we are all familiar with, oxide of iron and oxide of chromium, that play important parts as mordants, but there also is a great number of other oxides suitable for holding fast the dyes in the fibres of fabrics. There is, for instance, oxide of tin, which is used in the form of a solution of chloride of tin, or as it is commonly called *tin composition.*

Tin is not a very cheap metal to-day, and in former times it was extremely costly. Nevertheless this metal began to play a great part in dyeing after the discovery, made accidentally in 1640, in Holland, that the most beautiful scarlet the world had seen was produced by dyeing with cochineal after mordanting with a solution of tin; and the importance of tin increased when it was found at a later time that it had the property of increasing the brilliancy of many other dyes. Although more beautiful scarlets have been dyed in the last ten years or so by the use of aniline colours than could be obtained from cochineal, nevertheless tin has retained its importance in the dyeing industries because it is an extremely suitable reagent for fixing the most different kinds of dyes.

Besides the metallic oxides which are precipitated in the fibres of goods, and concerning the chief of which we have now learnt something, there is another important mordanting material known as *tannin*.

Tannin forms lakes directly with solutions of various dye-stuffs, so that goods can be dyed with the help of tannin. In addition to this, goods that have been treated with tannin are sometimes passed through solutions of alumina or other similar oxides ; compounds of tannic acid with alumina (or the other oxide) are thus formed in the fibres, and if after this double mordanting the goods are dipped into various dyeing solutions lakes are formed that are composed of tannin, metallic oxide, and the dye. With the help of tannin most remarkable results can now be obtained.

We said above that no practicable method for dyeing cotton goods without using mordants existed before the year 1884, and that however simple may be the theory of mordants the process of dyeing by their use requires much practice. For instance, it is a very difficult matter to fix the celebrated red dye known as *Turkey red* on cottons. This kind of dyeing is especially distinguished from others by the fact that oil must be added to the mordants that are to be employed. The mordanted fabric is dyed in a bath of *alizarin*, a dye-stuff to which we shall return again. This process of dyeing has been long known in the East ; but it has been fully developed only in Europe, and the cotton goods dyed in this manner in Europe have overrun the East. Enormous numbers of handkerchiefs, more especially, dyed in this way are sent to the Eastern markets.

This industry was naturally much menaced when a new red suddenly appeared, called *congo red*, which dyed cotton directly. Suppose an Indian woman wants a red cloth, she need only dissolve a little congo red in water, soak the piece of cotton in the liquid for a short time, and then draw it out dyed red. This red it is true is not nearly so fast as Turkey red; but that does not matter, as a repetition of the very simple process will bring the cloth back again to the desired colour. Colours which will dye without the employment of mordants are called *substantive colours.* Congo red was the first cotton-dyeing substantive colour known; it has been followed by very many others of all varieties of shades.

Substances known as *diazo compounds* have long played an important part, as intermediate products, in the chemistry of the colours obtained from coal tar. Compounds of this class are extremely ready to enter into chemical change; and while people were engaged in one place in experimenting on the applications of colours prepared by the help of these compounds rapid advances were being made in other places. Compounds can indeed be obtained which contain the diazo group twice, and which must be still more chemically energetic than their analogues that are but half as richly endowed as they. Individual bodies of this kind have long been known to science, and they have been employed in purely theoretical investigations. The examination of those compounds that bear the class names *bisdiazo*, or *tetrazo*, compounds for the purpose of finding whether they were capable of technical applications led to the discovery of those colouring matters that dye cotton directly.

Lack of preliminary knowledge makes it impossible for us to go deeply into the consideration of the *coal tar colours*, or, as they are generally called, the *aniline colours.* Indeed this lecture will be fully understood only by those who have a wide and full chemical knowledge. It should be stated clearly that these colours are not coal tar colours in the sense wherein this term is generally used by the public. Tar, that thick, black mass, cannot be worked up directly into colours.

The coal tar is first of all distilled; for this purpose we may employ an apparatus like that we made use of in distilling wine (see p. 26). When the tar is heated in such an apparatus clear, water-like oils pass over for some time, just as spirit distilled over from the wine. These oils form a part of the material from which coal tar colours are manufactured; after these oils distillates come over which partially solidify on cooling. *Carbolic acid* is obtained from these, and later on also *naphthalene* and many other bodies, among which we need mention only *anthracene*, as that is a substance we shall have to speak of again. If the process of distillation has been carried on long enough a solid mass resembling coke, and which can be used for burning, remains in the distilling vessel.

Before considering alizarin, which is the most important colouring matter derived from anthracene, we must speak of *indigo*. This blue dye has been known from the remotest times, and has been made from the juices of several nearly allied plants which grow in India; the juice is itself colourless, but when it stands in the air a process of oxidation occurs and indigo separates.

There is a European plant called *woad*, from whose juice indigo separates on standing; but the quantity of indigo so obtained is only about three-tenths of a per cent., which is very much less than is got from the Indian plants. In olden times, however, because of the slight connection between Europe and the East, woad was used exclusively in Europe; and as there was a very considerable demand for blue dyes the trade in woad blue reached considerable dimensions in some districts, and led to the amassing of large fortunes.

In the year 1300 there was a large trade in the neighbourhood of Erfurt, where those burghers who alone had the right to grow woad were known as *woad burghers*. Even as late as 1600 several hundred villages in Thuringia were occupied in the cultivation of woad. But at last the trade could not compete with that in the cheaper Indian indigo, although both Princes and States attempted to save it, not only by imposing protective duties, but also by prohibiting the importation of indigo. The Nürnbergers, for instance, were long accustomed to swear to their fellow-townsmen every year that no foreign indigo would be used in their manufactures. Indian indigo still controls the markets of the world; but it is not very probable that it will continue to do this much longer. In the first place blue dye-stuffs have been prepared from tar which are able to compete with indigo; and in the second place the problem of the artificial preparation of indigo has been completely solved in the laboratory in a series of wonderfully penetrating researches. The preparation of indigo by these methods, starting from coal tar, at present, however, costs more than the price of the natural substance. But many other methods have already been worked out for the synthesis, that is, the artificial production, of indigo ; and it is certainly probable that a method will be found which will enable indigo to be manufactured at such a price as shall make it possible for it to compete with the natural article.

As regards indigo, although on the one hand it is true that the improved relations of trade between India and Europe have driven out of cultivation in this part of the world a European plant which yields a dye, yet on the other hand we know that the advances made by chemistry in the production of dyes in the laboratory, and in connection therewith in factories also, have made the cultivation of another similar plant unprofitable in any part of the world.

This has been the case with *madder*, with which very different colours, but more especially a very beautiful red, can be dyed. This plant was cultivated throughout the whole of Southern Europe as far north as Baden, and also in Asia Minor, and in other places. The roots of this plant were used in dyeing, and these were known in the East by the name *alizari*, from which our word alizarin is derived.

These roots contain a number of dye-stuffs. Although very painstaking investigations into the chemical nature of these substances had been in progress since about 1823, the difficulties of the inquiry proved so great that but little progress was made for many years. It was not till the year 1868 that the connection was established between alizarin, which is the chief dye-stuff in madder roots, and the hydrocarbon anthracene which is contained in coal tar. At a later time alizarin was shown to be chemically a *dioxyanthraquinone*; and this knowledge led to a method for converting anthracene into this dioxyanthraquinone. At once all the energies of the trade were devoted to the preparation of this dye-stuff.

The methods that were at first made use of in the laboratory were found to be unsuitable on the large scale, hence these methods had to be replaced by others; but, after the expenditure of much labour, the manufacture of artificial alizarin has at last become so perfect that it can hardly be improved upon, and the natural product is no longer able to compete with the artificial substance in the matter of cheapness.

When the manufacture of artificial alizarin was introduced it was more especially praised on the ground that it would enable large tracts of land which had been used for growing madder to be again devoted to raising corn. But we cannot now share in that extolling of the secondary advantages that were to arise from a great advance in the domain of chemistry; for there is now such a superfluity of corn that agriculture is for ever on the outlook for more remunerative objects of cultivation. The fundamental conceptions of rural economy have indeed undergone great changes in the last five and twenty years. It has already been mentioned that a series of colours can be obtained in dyeing with madder, and also with alizarin; the final colour depends on the mordant that is used. Alumina mordants produce red dyes; iron mordants give dark tones, passing into black when much iron is used; chrome mordants dye violet, and so on.

Very remarkable results can be obtained by the use of alizarin. If, for instance, a piece of cotton goods is soaked in different mordants successively, hardly any change is made in the appearance of the cotton when it is dried. But if the material is now dipped into boiling water wherein a little artificial alizarin—which is a yellowish paste—has been dissolved, and, after remaining there for a little time, it is then washed in much water, the cloth shows a complete scale of colours.

Alizarin comes into commerce in the form of a paste which contains a large quantity of water, because dried alizarin is but slowly dissolved by water.

We have still to mention the extracts from woods that have been introduced in recent times into the dyeing industries. Aqueous extracts of various woods, such as logwood or Brazilwood, produce colours on mordanted fabrics, and are therefore useful for dyeing purposes. In order to save cost of transport these aqueous extracts are generally concentrated by evaporation (in the same way as was described under tanning extracts, p. 144) at the seaport towns, and the dyer uses the concentrated extracts thus prepared.

The coal tar colours are dangerous competitors against these extracts, and it is not unlikely that they may drive the extracts out of the field. At the present time more than three hundred different coal tar colours are used in dyeing, and the most varying shades of colour are obtained from these by using different mordants. But that number is very small compared with the vast array of colours of this kind that has been prepared. But the demands for fastness in colours, as regards the action of light and washing, have become so much more stringent of late years that it is only those colours which completely satisfy these demands that have any chance of finding technical applications.

Finally a word must be said regarding dyeing goods in designs. The custom used to be to imprint the designs directly on the goods. Then the method was discovered of covering the parts which it was desired should remain undyed with some substance that was not permeable by the dyeing solution. Such a substance was generally prepared by melting together resin and wax; when patterns had been stamped on the cloth with this material the whole was dipped into the dying bath, and the goods came out showing white patterns on a coloured ground. This was followed by the method of printing the patterns; the designs were cut in wood, the wood was covered with the colouring matter by the use of a cloth on which the colour was spread, and the wood was then pressed down upon the goods. The method was practically the same as that used in everyday life for imprinting a name cut in a stamp (which is nowadays generally made of caoutchouc) on to paper.

Calico printing has, however, for many years made use of machines, which have now been brought to great perfection. There are automatic machines in use to-day which are able to imprint sixteen different colours in succession on the same fabric.

LECTURE VIII.

Oil painting.—Drying and non-drying oils.—Linseed oil.—Varnishes.—Inks. — Cellulose. — Paper. — Sizing paper.—Straw boiling.—Esparto grass boiling.—Soda cellulose.—Sulphite cellulose.—Patents.

The process of printing designs on goods, which we spoke of at the close of the last lecture, leads us to consider painting itself, wherein prepared colours are mixed with such a vehicle as size and are then laid on to the surfaces that are to be coloured.

What are called *water colours* are fairly satisfactory; but they leave much to be desired, especially because they cannot be used in the open air, as if they get wet the colours run.

There is this difference between painting, whether with water colours or in oils, and dyeing, that organic colouring materials—to which class the coal tar colours belong—are but little used in painting, because such colours do not sufficiently resist the actions of light and weather to which oil colours are often exposed.

Almost all the colours used in painting are inorganic substances; these are affixed to a basis of some kind by the help of an oil. Suppose, for instance, that a brick has been ground to very fine powder; this powder will represent an almost indestructible red colouring material. No one would use this particular colouring matter, because it is not sufficiently beautiful; but coloured materials are found in nature, or are prepared by strongly heating or melting different substances, and these can be made ready for use in painting by grinding in the same way as was done with the brick. If, for instance, cobalt is added to glass during the process of manufacture, and if the resultant blue mass is finely ground, the extremely stable colouring material called *smalt* is obtained. Again, many of the precipitates that are formed when solutions of two salts are mixed are available as colours; yellow chromate of lead, which is used under the name of *chrome yellow*, for instance, is prepared by mixing solutions of chromate of potash and acetate of lead.

The following points are to be noted in connection with oil painting. Oil colours cannot be prepared with all kinds of oil. If the colours were rubbed up with olive oil, for instance, the products would not dry, as olive oil leaves what are called fat spots—that is, spots which never completely dry up.

The oils fall into two main classes—drying and non-drying oils.

The chief constituents of the non-drying oils, including olive oil, are two substances about which we already know something (see p. 21)—namely, oleic acid and glycerin; and this oleic acid is identical with that which enters into the composition of such animal fats as ox tallow. In the drying oils oleic acid is replaced by other acids the names of which are generally derived from the names of the oils in which they occur; linseed oil, for instance, which is one of the drying oils, contains *linoleic acid. Linseed oil* is obtained by pressing linseed. We know that seeds contain large quantities of oil (cf. p. 61); linseed [seed of the common flax] is especially rich in oil, about 22 per cent. of oil being obtained when the seeds are pressed cold, and about 28 per cent. when they are pressed hot.

Neither kind of oil can be kept for a long time in the air without undergoing change. Olive oil and similar oils become rancid, and the drying oils change into hard, transparent masses, especially if they are spread out in thin films. When an oil becomes rancid there is a partial decomposition into free fatty acids and glycerin; these changes are thought by some to be brought about by moist air alone, while others suppose that the presence of a bacillus is also necessary. The solidification of the drying oils depends simply on a process of oxidation, whereby linoleic and similar acids are completely changed.

It should be noted that some oils, such as cottonseed oil, contain both ordinary oleic acid and another, drying, oleic acid. Such oils are distinguished as badly drying oils, a name which explains itself.

It is a very remarkable fact that the drying oils dry distinctly more rapidly when their oxidation is started artificially—when they are boiled, for instance, with a substance such as lead oxide which gives up oxygen. Linseed oil which has been boiled with lead oxide or with a similar substance—and some of these substances, borate of manganese for instance, are said to be very efficient—is used for rubbing up with colouring materials to form the oil colours that are used in oil painting.

Linseed oil prepared as described may be spread over any selected surface, which may or may not have been already treated with water colours; the oil then dries to a very hard, glassy, transparent skin, and the surface is said to be varnished.

The term *varnish* has, however, a somewhat wider signification. The term is taken generally to mean, not so much boiled linseed oil, as solutions of resins in that oil or in some medium which readily evaporates. Such solutions in very volatile media are sometimes called lakes [in Germany].

A solution of *shellac* in alcohol is used as a varnish which dries very quickly, as the spirit rapidly evaporates when exposed to the air. Spirit varnishes are, however, much less approved of than solutions of resins in turpentine oil, because the thin coatings which remain when the latter evaporate are much firmer than those left by spirit varnishes.

The most lasting varnishes are obtained by dissolving *amber* or *copal* in boiled linseed oil. Amber, which is a fossil resin, must be melted before being dissolved, as raw amber is insoluble in boiled linseed oil. Copal is also a resin. Many plants contain characteristic liquids which flow from the plants, either spontaneously or when the plants are cut, and become solid on standing in the air; these solidified masses are called resins. The copal of commerce is obtained from a great many different trees that grow in hot climates. Small quantities of it are also dug from the ground on the east coast of Africa; some say that this copal is a fossil, others that it has exuded from the roots of plants.

We must now consider that colouring fluid which is used more frequently than any other, namely, *ink*.

The old fashioned black ink is a compound called *gallo-tannate of iron* suspended in water. It is prepared by adding a solution of sulphate of iron to an aqueous decoction of galls. A little gum solution is always added, to make the ink of a better consistence for writing, and also to secure the more complete suspension of the black precipitate. A finer looking black colour is procured to-day by mixing a little logwood with the galls before extracting with water, and then adding sulphate of iron and gum.

The manufacture of inks has been made much easier by the discovery of aniline colours that are soluble in water. Black ink is obtained by dissolving *aniline black* or *indulin black* in water. A solution of fuchsin forms a red ink, and a more beautiful red ink is obtained by dissolving *eosin* (ἠώς = the morn) in water. The favourite violet ink is prepared by dissolving 1 part aniline violet in 300 parts of water, and adding gum solution, etc. Copying inks differ from ordinary inks only in that the former contain more gum and also some sugar; so much of the ink then adheres to the paper which is written upon that a readable impression of the writing can be obtained in the copying press.

We shall mention here the so-called *sympathetic inks*, although these play a more important part in exciting the fancy in romances than in real life. If characters are written on paper with a solution of yellow prussiate of potash, for instance, nothing is to be seen when the writing becomes dry, because the salt has only a very slight yellow colour; but if a person who is in the secret brushes the pages over with a pencil dipped in a dilute solution of chloride of iron the writing stands out vividly in blue letters, because the two ingredients have reacted to produce Prussian blue (see p. 155). It is possible in this way to cause writing to appear in almost any colour by a proper choice of two liquids, either of which is colourless or nearly colourless when taken alone, but which react together to produce dark coloured precipitates.

The true sympathetic ink should, however, be more secret than this. In the cases we have spoken of the writing remains legible once it has been developed, but what is desired is that the writing should fade away after it has been read by the recipient of the letter. Such an ink is generally made from a solution of chloride of cobalt or chloride of copper. A solution of the first of these salts is almost colourless, and writing traced with it is invisible on white paper. But if the paper is warmed the compound gives up water which it has been holding in chemical combination, the deep blue anhydrous chloride of cobalt is produced, and the writing is very plainly seen. The writing disappears again as the paper cools, because enough water is absorbed from the moist air to cause the re-formation of the colourless hydrated compound. If the writing is done with a solution of chloride of copper, which solution has only a very slight bluish colour, and the paper is afterwards warmed, the written characters come out in a yellow brown colour, and they vanish again on cooling for the same reason as holds good in the case of chloride of cobalt.

We shall meet with an insoluble ink when we are describing the processes of photography.

We must now proceed to the subject of *paper*.

In the oldest times the only materials used for writing on were those furnished by nature, such as stones, pieces of wood, or skins; but the Egyptians very long ago discovered how to prepare paper from the *papyrus* plant. The stalks of that plant were cut into as thin and wide leaflets as possible, and these were placed side by side; a second layer of similar pieces was arranged transversely over the first, and the whole was placed under a press, where it dried together to a single sheet. This was then rubbed as smooth as possible and was ready for writing on.

Besides this writing material, parchment (see p. 148) was used by the ancients and in the earlier Middle Ages, until what we now call paper was discovered in the eleventh century. The paper we use nowadays consists of thin layers of very strongly felted vegetable fibres; fibres from animal sources are not suited for this manufacture.

That paper might be made cheaply, it used to be the custom not to make direct use of the fibrous material as it came from the plants, but to employ in the manufacture the vegetable fibres in the rags that remained when linen and cotton goods had become worn out by use.

Accurate investigations have shown that all such fibres consist of cellulose and other substances which surround, or incrust, the short fibres of the celluose.

Pure cellulose is a carbohydrate (see p. 66); it consists of six atoms of carbon, ten atoms of hydrogen, and five atoms of oxygen. The number of the atoms in cellulose is the same as in starch; but cellulose is not a nourishing food inasmuch as it is quite indigestible.

The manufacture of paper was originally conducted as follows.

Wet rags were allowed to semi-putrefy for two or three days, whereby the substances that incrust the cellulose were so far dissolved that, when the rags were then beaten in the presence of much water, the short fibres of the cellulose became sufficiently apparent. The pulp that was thus obtained was then thrown on to a fine sieve which was shaken to and fro by a workman. The greater part of the water drained off through the sieve, and there remained a thin felted layer of cellulose fibres formed by the interweaving of the single fibres. This was at once removed by a second workman to a thick felt, where it was covered with another similar felt; and, when a sufficiently thick pile had been built up, the whole was placed under a press, in order to remove as much water as possible, and at the same time to give solidity to the individual sheets of paper. The sheets were then taken out of the felts and were thoroughly dried.

Paper made in this way has a loose texture like blotting paper. It can be used for printing on or as packing paper; but it is not suitable for writing on, because the ink is absorbed and spread by the little fibres, and the writing runs. Paper made in this way is also not at all durable.

In order to give greater consistency to such paper, and also to fill up its pores, it is submitted to an operation called *sizing*, a term which does not accurately express the operation in question. For if size were added alone to a paper pulp containing much water most of the size would go into solution, and would pass through the sieve, and only an insignificant residue would remain in the finished paper. But if alum is added besides size to the paper pulp a different result is obtained. In considering both tanning and dyeing we have learned to recognise the great affinity that alum has for fibres. Here also the same cause is at work; the fibres of the paper hold the alumina, and that in turn prevents the removal of the sizing material. When both alum and size have been added to the paper pulp, then the washing in the sieve does not remove the size, as it is held in the fibres of the pulp by the alumina. When the paper is now dried the fibres adhere together, and a paper is produced which can be written on, as the fibres have lost their capillarity; the size in the paper being insoluble in water also makes the paper less sensible to the action of moisture.

The procedure in making paper by hand was to prepare unsized paper, then to draw this through solutions containing alum and size, and finally to dry. The surface of paper prepared by hand on a sieve cannot be very smooth; hence all hand-made paper must be glazed after it is made, in order to give it a good appearance. For this purpose the paper is either pressed when moist between flat surfaces, or it is glazed by passing between two highly polished rollers whereby it acquires a perfectly smooth surface. Hand work in paper making has been gradually and completely replaced by machines; and while formerly the single sheets could not be larger than the largest sieve that a single workman was able to manipulate, the machines produce sheets of very considerable width and of any length that may be desired.

In making paper pulp from rags it is not now the custom to beat the rags after a slight putrefactive change has taken place in them. The rags are nowadays prepared as far as possible for disintegration by boiling with a strong alkali—caustic soda, with which we shall become better acquainted when we come to the soda industry, is used; they are then placed in a rectangular vessel in which revolves a roller set with knives which pass near stationary knives fixed in the sides of the vessel. Such an apparatus, called a "breaker," with its rollers driven by mechanical energy, reduces the rags to a state of fine division, and grinds them up with water to a pulp.

This pulp is then bleached by chloride of lime, and the harmful after effects of the bleaching material are neutralised by the use of an antichlor (see p. 151). The next thing to be done is the sizing. Glue is not now used for sizing machine-made paper; but suitable resins—colophony resin, for instance—are boiled with caustic soda lye, and the soaps thus produced (see *soap* in the next lecture) are added, along with alum, to the pulp. The alumina of the alum being held by the cellulose fixes the constituents of the resins, and these bind together the fibres in the paper, and so make it suitable for writing on.

The pulp being now ready for making into paper is caused to flow on to an endless wire cloth, made of fine brass wire, care being taken to dilute the pulp to the proper consistency by a plentiful supply of water; the wire cloth is caused to travel constantly in one direction by means of rollers. A vibratory motion is at the same time communicated to the wire cloth, for the purpose of aiding the felting of the short fibres of the pulp; and any design that may be woven into the wire cloth appears as a water-mark in the finished paper. The paper pulp from which most of the water has already drained off is now seized by an endless felt which carries the pulp with it; a second travelling felt soon meets the first, and the pulp is pressed between these by a pair of rollers, and is thus nearly dried. The pulp now passes on to a polished cylinder which is kept hot so that the paper is dried and at the same time receives a perfectly smooth surface; a second cylinder serves to impart an equally glossy appearance to the other side of the paper. Finally the machine makes up the finished paper into rolls.

It has been found impossible for many years to manufacture from rags alone sufficient paper to meet the enormous demand. A consideration of the great number of newspapers published in these days shows how impossible it would be to make paper enough from that single source; and it must be remembered that much less waste linen or cotton is obtained from each individual than corresponds to the consumption of cellulose per head, be it for writing paper or paper for printing newspapers on. As early as the last century export duties were levied on rags in many countries—in Prussia, for example—in order to make it easier for the home factories to obtain supplies of this material. But a measure of that kind was not of itself sufficient to cause an increase in the supply; and so the paper-makers began to look about eagerly for a suitable substitute for rags. The result has been that the great advances made in chemical knowledge enable many paper factories to be carried on to-day without using any rags at all.

It sometimes happens that paper not made from rags is so bad that it is refused by the public, just as such paper was refused at an earlier time ; but the special methods of working with cellulose have been so developed that, although when this industry was in its infancy it might be said that cellulose was merely a makeshift for rags, we find to-day that cellulose has virtually superseded rags in the paper factories.

A little consideration shows that it is very likely that cellulose should be found in many other plants besides in that from which linen is made. But it is possible that although the chemical composition of cellulose from different sources may be the same, nevertheless the physical properties of the celluloses may differ (cf. what was said about starches on p. 68). When straw is properly treated it yields a cellulose ; and a very convenient form of cellulose is obtained from *esparto grass*, which is a plant that grows wild in North Africa, especially in Algiers.

It is to be noted that although every tree, and therefore every kind of wood, must contain cellulose, nevertheless the attempts that have been made to manufacture paper from wood have not been very successful. It happens that wood was the substance tried in the earliest attempts to find a substitute for rags.

In the year 1846 a process of wood grinding was introduced in South Germany. The method is very simple ; selected logs are held against a wet millstone until they are ground to powder. The pulp that is obtained in this way has not, of course, exactly a fibrous structure; its readiness to be felted is very small. And besides this, it is full of resins from the trees from which it has been made, and this makes the bleaching of it very difficult if not impossible. This wood pulp can only be worked up with rags, the longer fibres of which give the needful tenacity to the paper, while the wood pulp increases the weight. This substance is indeed rather a "loading" than a substitute for rags.

The employment of such loading stuffs has been carried much further. Gypsum, and substances of like nature, are mixed with the paper pulp; such substances cannot, it is true, improve the felting of the pulp, but when they are deposited between the felted fibres of the paper they add to the weight, although at the same time they reduce the strength, of the paper.

Besides the purely mechanical process of grinding wood, a method was introduced, almost at the same time, into the paper industry for disintegrating straw by boiling it with alkali, and so obtaining a product which, after thorough washing with water, could be at once reduced to pulp in a "breaker." The cheapest alkali, and that which is used for this purpose, is caustic soda lye (see Lecture IX.). The pulp that is obtained from straw can be bleached by chloride of lime, and it may then be mixed freely with the genuine cellulose that is used in the paper factory. A pulp is obtained by a similar method from esparto grass.

While the disintegration by boiling of straw or esparto grass, and like substances, is easily carried out, the performance of the same process with wood is much more difficult because we are dealing with a vastly more solid material. The process at first adopted as the most convenient was what is known as the soda cellulose treatment. This process consists in boiling wood, chiefly fir and pine wood, with soda lye under a greatly increased pressure. The vessels are placed, like steam boilers, directly over the fire. The raw material is cut in thin shavings perpendicularly to the stem, and these are placed, in wire supports, in the vessels into which the lye is then run. As the pressure must be got up to about ten atmospheres, in order to effect the complete breaking up of the wood, the plates of which the vessels are made are fastened together by a triple series of rivets. When the boiling is finished the wood shavings appear dark brown. As all the substances that incrust and hold together the cellulose in the wood have by this time become soluble in water, these substances are dissolved and removed by stamping the shavings in large quantities of water, in a suitable apparatus; and, after washing, only the cellulose remains. The product, called *soda cellulose*, comes into the market with fairly long fibres, and as it is easily bleached it is used for working up with other materials into paper.

The substance known as *sulphite cellulose* has been a keen competitor against the soda cellulose since the year 1884, and has gradually superseded it.

It is of course perfectly conceivable that there should be other substances besides soda lye capable of disintegrating the bodies that incrust the cellulose in woods, without exerting too much action on the cellulose itself. Many such substances have been discovered in the course of time, but the only one that has been found technically useful is *acid sulphite of lime.* The name sulphite cellulose is given because the reagent used in the process is a sulphite—that is, a salt of sulphurous acid.

The process of making sulphite cellulose was made technically practicable by a German inventor; although experiments in the same direction had been made before him by others, yet these experiments led to no results. There is indeed an English patent dating from 1866 wherein the whole process is nearly described, but only nearly, for never did a pound of cellulose made by that patent come into the market.

Nothing can be included in a German patent that has been described by any one, anywhere, in the same or in a very similar manner, until after fifty years have elapsed since the last publication. The conditions are therefore very unfavourable to the discoverer. We know from what we learnt about tanning that almost all woods contain tanning bodies; these substances must go into solution, along with the other non-cellulose constituents of the wood, when wood is disintegrated to cellulose by boiling. Hence these substances must be found at last in the aqueous liquid, provided they are not decomposed by the special process of boiling that may have been used. The specification of the patent therefore stated that a liquor could be obtained by boiling wood with acid sulphite of lime, which liquor was serviceable for tanning purposes, while cellulose was obtained as a bye-product.

But now, what is acid sulphite of lime?

We all know that when sulphur is ignited it burns with a very penetrating odour, and gradually disappears, and just as carbon produces the gas carbonic acid when it burns, so burning sulphur forms sulphurous acid, which is also a gas. Acids combine with bases to form salts (see p. 51); if, then, the gas coming from a furnace in which sulphur is burning is led into a chimney, that is not empty as chimneys usually are but is filled with limestone which is kept moist, the sulphurous acid will not escape into the air, but will combine with the basic lime to form sulphite of lime. As there will be much sulphurous acid gas at the bottom of the chimney, and as this gas is very soluble in water, an acid solution of the gas will be produced at this point, and the sulphite of lime that is formed will dissolve in this acid liquor to form acid sulphite of lime.

The preparation of the solution of acid sulphite of lime by working with a tower filled with chalk was also patented, because, although the salt had long been known in chemistry, no one had prepared it by this method; the process of preparation was new.

A solution of acid sulphite of lime attacks most metals energetically. Lead is the metal which best withstands the action of chemical reagents, and at the same time is not too costly when it has to be used in considerable quantities; for this reason leaden vessels, or vessels covered with lead, are very often used in chemical industries.

If cellulose is to be prepared from wood by the action of the acid sulphite liquor, the wood must be boiled with the liquor under pressure. Now lead is so soft that it is impossible to make leaden vessels that will withstand much pressure; hence it was a very difficult problem to construct vessels suitable for carrying out the process of making sulphite cellulose on the large scale. At last the following method was found to work. An ordinary boiler was lined inside with resin on which were laid plates of lead; these plates were then covered with acid-resisting flagstones arranged in two layers in such a way that the joints between the upper and the under layers were separated from one another by half the breadth of one of the stones.

At first this mantle preserved the outer iron vessel from being corroded; but the lead is now entirely taken away, as it is found that the flagstones alone are a sufficient protection if they are joined by a suitable cement.

Four systems of leaden pipes were placed in the boiler for the purpose of heating it, and steam was led in through these pipes from another boiler. It was necessary to have several sets of pipes, because, as lead cannot withstand much pressure, one or other of the pipes might burst. This arrangement was improved by substituting iron pipes cased with lead for those made wholly of lead. But the makers of leaden pipes have been impelled by the demand to produce pipes that are strong enough without being lined with iron. Considering how great a space must be occupied by these safety appliances in the boilers, and knowing that a single boiling occupies about seventy-two hours in this process, it is evident that the boilers must be very large if the output of a factory is to be at all considerable. As a matter of fact the boilers are sometimes so spacious that it is possible to drive a horse and cart into them.

Wood which has been boiled with the acid sulphite of lime liquor leaves the boilers less coloured than when it went in; in this respect it differs from wood boiled with soda lye. Remembering that sulphurous acid is an effectual bleaching agent (see p. 153) we see that there can be no difficulty in turning out perfectly white cellulose by this process.*

The best product is obtained from the wood of the silver fir. This tree does not flourish farther north than the Main; and as the trees are most suited for cellulose making when they are about fifteen years old, and the demand has greatly increased of late years, the planting of these trees is a matter to be commended to the consideration of the managers of forestry.

Sulphite cellulose soon began to compete keenly with soda cellulose. The makers of soda cellulose tried hard to upset the patent, alleging that the specifications were misleading—no tanning materials prepared by this patent have yet come into the market (see p. 180)—and harking back to the older English patent. The result was that the German patent was declared to be nugatory, except in so far as the preparation of acid sulphite of lime by the use of towers was concerned, as it was held that this process had never been described before by any one. The sulphite cellulose factories then remained dependent on the inventor of the towers, as without these towers no lye could be made for use in the factories. But this was changed at a later time when other methods were discovered for making the necessary lye.

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* I cannot avoid referring to a very remarkable fact that is often repeated in the practical conduct of methods based on chemical reactions—to the fact, namely, that a process brought about by the use of alkalis may also be accomplished, after making the necessary changes in the procedure, by the employment of acids which are compounds chemically opposed to alkalis. An example of this fact is found in the sulphite cellulose process as compared with the soda cellulose process; and the following is another example. Accumulators of electrical energy, which store up electricity somewhat as the gasometer stores the gas in a gas works (cf. p. 30), are made of metallic plates and plates of metallic oxides, and these plates have hitherto been suspended in dilute sulphuric acid; but in the most recent form of accumulators a solution of zinc oxide in caustic soda is used as the liquid, and this solution is strongly basic as contrasted with the sulphuric acid that was formerly employed. Accumulators made with this alkaline liquid are very well spoken of, but they will certainly have to stand the test of practice. We shall meet with further illustrations of this phenomenon in the lecture on photography.

All the disputes about this patent, which were of the greatest interest to those who took part in them in the year 1880, have now fallen to the ground; patents remain in force [in Germany] for fifteen years, and as the patent in question was registered in 1878 it ran out in 1893.

Sulphite cellulose is more and more driving out soda cellulose; and many factories that used to produce soda cellulose have been altered and are now producing sulphite cellulose. Not only this, but sulphite cellulose is slowly taking the place of the raw material that was formerly employed in paper making, so that linen and cotton rags are less used than they were, and every year makes it more difficult to find a market for these materials.

Finally it should be mentioned, as showing the superiority of the cellulose made by the sulphite process that some very skilful workers are now making attempts so to disintegrate wood that cellulose may be obtained in such long fibres that it may be interwoven with cotton and thus serve as a partial substitute for that material.

It is of course impossible to say whether these attempts, which have been in process for some years, will or will not be crowned with success; but they show us what great expectations some people have of the future of the sulphite cellulose.

LECTURE IX.

Potash.—Soda by Leblanc's process.—Sulphuric acid.—Sulphate of soda. — Nitric acid. — Bleaching powder. — Manganese recovery process.—Soda crystals.—Sulphur recovery.—Ammonia soda process.—Ashes of molasses.—Ashes from the washings of wool.—Soap.—Caustic alkali.—Caustic soda.—Soft soaps.—Loaded soaps.—Curd soaps.—Hard and soft waters.—Plasters.

THE preparation of *soaps*, which we have now to consider, is brought about by the action of caustic alkalis on fats. Before we are in a position to deal with soaps we must consider in some detail the caustic alkalis, and also the carbonated alkalis, as the manufacture of one of these cannot be separated from that of the other.

The burning, or, to speak more accurately, the intense heating, of limestone was practised in ancient times; and in these days burnt lime was the only caustic alkali known throughout the world.

The product of this burning was called *caustic lime* because of its caustic properties. We shall learn more about this process later in this lecture (see p. 201).

Caustic lime is only slightly soluble in water. But even in the early Middle Ages a method had been discovered for using caustic lime to make an alkali that was very soluble in water; this alkali was *caustic* *potash*, a substance which was, and is, made from potashes. And potashes is obtained as follows. We know (see p. 39) that all land plants must have potash salts if they are to live; every kind of wood, for instance, contains potash salts, and when the wood is burnt these salts are found in the ashes. The ashes of plants contain potash salts chiefly as *carbonate of potash*, which is a salt that is very soluble in water. If the ashes are boiled with water in pots the potash salts go into solution, and when this solution is evaporated these salts are found in the solid residue, which is known as potashes (or pot-ashes).

Potashes is a substance that was, and is, very much used; it is employed, for instance, in making soap, in manufacturing glass, in dyeing, etc. As forests were cut down the supply of potashes became less; this narrowing of the supply made itself definitely felt at first in France, where, as long ago as 1775, the Academy of Paris offered a prize of 2,500 *livres*, not for a process for making potashes artificially, but for a method whereby common salt could be converted into soda, because soda could be used, in most cases, as a substitute for potash.

Matters were in this position. Potashes is carbonate of potash; soda was also known to be a carbonate. No natural source of potash was known other than potashes. The Stassfurt salt deposits (see p. 48) were not discovered till the second half of the present century; and there was no method known at that time for making potash from other compounds of potash.

The only source of soda salts available at that time was the ash of sea plants, which plants contain soda in place of the potash of land plants; this ash was prepared chiefly in North Spain, and was known as *barilla*. The greater part of the *barilla* of that time consisted of impurities; only about 5 per cent. of soda was present in it. Nevertheless so great was the demand, or we might say the greediness, for soda that this *barilla* was used in various industries. Now soda is *carbonate of sodium*, and it was known even in these days that in *common salt*, which is composed of sodium and chlorine, there is a practically unlimited supply of sodium compounds. And so it was that a prize was offered for a method of making soda from salt, because there seemed to be no possibility of finding a process for manufacturing potash salts.

The following figures give a notion of the value of soda salts. In 1814 a ton of soda crystals cost about £65; in 1824 the cost was about £32; and at present it is about £5. The prices that ruled at the time we are speaking of made possible a very large profit on the manufacture of soda.

After many unsuccessful attempts by other people, the problem was solved by Leblanc, who took out a patent in 1791 for the process which has continued to be used until now.

Leblanc's method appears to be extremely complicated. To conduct the process at all requires chemical knowledge of the most varied kind; and to apply the improvements that have been worked out in the laboratory, and to carry into practice the many subsidiary manufactures that have sprung from this main industry, demand so much technical ability that it may be said that this manufacture is not merely the foundation of the immense chemical industries of the present day, but is also the guiding spirit in these industries.

Those discoveries which have made possible the almost fabulously complicated processes that are now carried out technically, and those methods that have led to the establishment of chemical works wherein aniline colours, or artificial febrifuges like *antipyrin*, or artificial scents like *vanillin*, are manufactured, rest in part on knowledge gained in the soda industry, and in part are developments from that industry. The advances that have been made in recent times in the industries connected with soda making have left all former advances farther behind than could have been supposed even by those endowed with the liveliest fancy.

Leblanc's process consists of the following parts. Common salt (chloride of sodium) is changed into *sulphate of soda* by heating with sulphuric acid. The sulphate of soda is then mixed with coal and chalk (chalk is carbonate of lime), and the mixture is heated until it melts; the melted mass is lixiviated with water, and the solution which contains carbonate of soda is evaporated; the crystals that separate are the *soda crystals* of commerce.

The salt sulphate of soda, into which common salt is converted in the first stage of the manufacture of soda, is ordinarily known as *Glauber's salt*, from Glauber, who first prepared it in 1645.

The manufacture of soda requires the use of *sulphuric acid*; and the manufacture of this acid is intimately bound up with that of soda.

We know that gaseous sulphurous acid is produced when sulphur is burnt (see p. 181). Now to convert sulphurous into sulphuric acid an atom of oxygen must be added to the former. This cannot be done directly, but only in presence of *nitric acid*; experience has shown that the process is best conducted in large chambers, which are made of lead that they may resist the action of the acid (cf. p. 181). The nitric acid loses oxygen which goes to oxidise the sulphurous acid to sulphuric acid. As constant supplies of air and water vapour are led into the chamber, the products of the deoxidation of the nitric acid are constantly changed back into nitric acid; the nitric acid thus serves as a carrier of the oxygen of the air to the sulphurous acid, and hence a comparatively small quantity of nitric acid is required. The sulphuric acid collects as a liquid on the bottom of the chamber.

The manufacture of soda evidently carries with it the making of nitric acid. This acid is sometimes called [*aqua fortis*, and sometimes] *parting acid*, because it is used to part gold and silver, only the latter of these metals being soluble in nitric acid. The acid is made by the action of sulphuric acid on saltpetre, and soda saltpetre is used because of its cheapness (cf. Chili saltpetre on p. 52). The products of the reaction of these two compounds are nitric acid and sulphate of soda; the acid sulphate of soda is generally produced for reasons which to consider here would lead us too far afield.

Sulphuric acid used to be prepared in the manner indicated above from sulphur; but in the year 1838 the price of sulphur rose from £5 10*s.* to £15 per ton, because in that year the then King of Naples leased to a Marseilles firm a monopoly for making sulphur in Sicily, which is the only European country where sulphur is found in quantity. The English sulphuric acid factories—and almost all the factories at that time were in England—grumbled exceedingly, and a kind of sulphur war threatened to break out; the result was that the monopoly was withdrawn.

But meanwhile necessity had led to new inventions. It is true that there is not much free sulphur to be found in Europe; but there are enormous deposits of sulphur compounds scattered about the world, especially deposits of sulphide of iron which forms the mineral known as *pyrites.* Pyrites can be burnt in ovens; and under these conditions the sulphur of the pyrites—and pyrites contains about 48 per cent. of sulphur—is burnt to sulphurous acid, while the iron is burnt to oxide of iron which can be used in iron making. There is also the mineral *copper pyrites,* coming for the most part from Spain, which can be used for making sulphuric acid; this mineral is willingly employed by the sulphuric acid maker, because the extraction of copper from the burnt residue is a paying business. Here is an example of a subsidiary industry depending on the soda industry.

Sulphuric acid is one of those commercial articles which are manufactured in enormous quantities. Besides what is required in soda making, we have but to think what quantities of sulphuric acid must be used every year in the process of decomposing phosphorite and burnt bones to make them into artificial manures, and how much must be needed for manufacturing sulphate of ammonia for the use of the farmers (cf. pp. 46 and 52).

In 1891 there were produced in the German Empire about 680,000 tons of sulphuric acid, equal to about 175 railway truckloads per day; the value of this was about £750,000; about 150,000 tons were made from German pyrites, and about 392,000 tons from Spanish pyrites, etc. Since 1891 the manufacture of sulphuric acid has considerably increased. [The output of sulphuric acid in Great Britain in 1883 was almost 1,000,000 tons; and the output in America was between 500,000 and 600,000 tons in 1891.]

When sulphuric acid reacts with common salt (chloride of sodium) not only is sulphate of soda formed, but hydrochloric acid is also produced.

Common salt + sulphuric acid = sulphate of soda + hydrochloric acid.

Hydrochloric acid is a gas, and like sulphuric acid or ammonia gas it is very soluble in water. Commercial hydrochloric acid, which is an aqueous solution of the gas, contains about 32 per cent. of the acid. This commercial acid is a liquid which fumes slightly in the air; when it is evaporated the hydrochloric acid gas that is given off forms clouds with the moisture of the air. In the earlier days of the soda industry no use could be found for the hydrochloric acid produced in the manufacture, and, as it was allowed to escape into the air with the gases from the furnaces, it formed a terrible nuisance. All vegetation died in the neighbourhood of the soda factories, and complaints were loud and deep. In a suburb of Brussels the tools of the artisans living there were so corroded by the acid as to become useless in a short time. An attempt was made in one factory to get rid of the gas by leading it up a chimney 150 metres [nearly 500 feet] high—that is, about twice the height of an ordinary church spire—but instead of mixing with the air at the top of the chimney, the gas fell, in wet weather, in heavy clouds on to the ground beneath.*

To stop the complaints some English factories were put out of the way on to small islands in the canals; but although the great solubility of hydrochloric acid in water was well known, there was no possibility of getting rid of the acid by this procedure, for the

* It may be noticed here that the reproaches which used to be brought against soda making, because of the large quantities of hydrochloric acid that were sent into the air, are now brought against every industry that uses much coal, and that notwithstanding all that has been done in the way of smoke consumption these complaints are still made. The sulphurous acid that goes into the air with the other products of combustion of coal is not destroyed even if the particles of soot are completely burned; that acid is rather changed in the air into sulphuric acid. We know that all coal contains sulphur, and that a little of this finds its way into our dwellings in the coal gas we burn (see p. 33). Official investigations have shown that 1,000,000 cubic metres of air in London contain 1,670 grams of sulphuric acid, that in Manchester the quantity of this acid rises to 2,518 grams, and that 2,668 grams are present in 1,000,000 cubic metres of the air near an oil of vitriol works. In the country, on the other hand, the figure is 474 grams. [731 grains per 1,000,000 cubic feet in London; 1,100 grains in Manchester; 1,166 grains near an oil of vitriol factory; and 270 grains per 1,000,000 cubic feet of country air.] The sulphuric acid in the air of the country arises chiefly from the decay of organic substances, for albuminoids contain sulphur (see p. 62). Calculating on the basis of the London numbers we find that a room 6 metres long, 5 metres wide, and 4 metres

aqueous hydrochloric acid could not be run into rivers as it would kill the fish.

Hydrochloric acid remained for long a veritable plague to the manufacturers; but gradually matters have so completely changed that the hydrochloric acid produced in the Leblanc soda process is at present the most valuable product of these factories: we shall learn later how this has come about.

This acid finds one of its chief employments to-day in the manufacture of chloride of lime, which is made in large quantities for use in bleaching (see p. 150). A little is used in making chlorate of potash and other similar salts. And large quantities of the hydrochloric acid produced in soda making are bought by other manufacturers for use in their various industries.

In order to make chloride of lime from hydrochloric acid the aqueous solution of the acid is heated with *pyrolusite*, a mineral which consists chiefly of peroxide of manganese; in this reaction between manganese peroxide, which is very rich in oxygen, and hydrochloric acid, which is a compound of hydrogen and chlorine, the oxygen of the manganese peroxide combines with the hydrogen of the acid to form water, and

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high would contain no more than two-tenths of a gram of sulphuric acid. [The quantity of sulphuric acid in a room about 19½ × 16½ ft. × 13 ft. high would amount to about 3 grains.] The acid in the air becomes especially harmful by the influence of the rain, which precipitates the acid on to the leaves of plants and so greatly retards their growth. Quite recently a protracted law suit was carried on between the owners of a smelting works in Upper Silesia and the proprietor of a neighbouring forest; the forest proprietor brought the action on the ground that his trees were being damaged by the sulphurous acid coming from the chimneys of the smelting works.

chlorine is set free; it is then only necessary to lead the chlorine into chambers wherein lime is spread in order to form chloride of lime. The manganese of the pyrolusite is finally converted into chloride of manganese by the reaction with hydrochloric acid; this chloride of manganese goes into solution, and, although pyrolusite is cheap—it is obtained by mining in large quantities—a remarkable process has been devised for recovering the manganese, in the form of manganese peroxide, from this solution, at an exceedingly small cost. This process is known as the *manganese recovery process.*

Every soda factory that works the Leblanc process also makes bleaching powder as a bye-product, and is provided with the very extensive plant for working the manganese recovery process.

For starting the first manufactory for carrying out his process Leblanc naturally required a large sum of money. The money was furnished by the Duke of Orleans, afterwards known as Philippe Egalité, on the strength of a report testifying to the soundness of the project by d'Arcet, professor of chemistry in the *Collège de France,* which is one of the two universities of Paris. Egalité's life was brought to an end in 1793, as the lives of so many others were at that period of French politics, by the guillotine, and the soda factory was confiscated along with his other possessions. After this the constant wars of the Republic, by preventing the transport of goods to the sea, caused potashes to become very scarce in France, and a decree was issued by *The Committee of Public Safety* commanding that all the processes for making soda that had been discovered (see pp. 187, 188) should be made known. In this way Leblanc's patent collapsed. The factory was restored to Leblanc in 1799; but he could not carry it on for want of means, and in 1806 this great inventor committed suicide in despair. Besides the intrinsic value of his own discoveries, the labours of Leblanc had a most important influence in developing many other industries, such as the manufactures of glass and soap. At a later time the French Government made a payment from the national exchequer to the grandchildren of Leblanc.

The process was not forgotten, but it dragged along without much effect until it was taken up and developed by some English manufacturers. The soda industry did not grow much, however, in England until after 1824, in which year the duty of about £30 per ton was removed.

The soda manufactured in London must for a time have been given away, in order to accustom the soapmakers to the use of soda and to induce them to give up the employment of *barilla* (see p. 188). But this state of affairs was soon changed, as it was found that the work of soap making was done much more quickly and conveniently by using the pure soda than when the unsatisfactory barilla was employed. Indeed after a time people were glad to get hold of the crude melted masses that came from the soda ovens, and to lixiviate these for themselves, rather than use barilla.

Soda had gained a firm footing. The manufacture of soda began in Germany in 1830 at Schönebeck on the Elbe.

To prepare soda by the Leblanc process it is neces sary to melt together Glauber's salt, chalk, and coal. The sodium that goes to make the soda is obtained from the Glauber's salt, and the carbonic acid from the chalk, which, as we know, is carbonate of lime. The reactions that occur in the process of melting are so complicated that it is not possible for us to go into them in this place. The soda (carbonate of sodium) in the melted product is dissolved out by lixiviating with water, and this solution is evaporated until less water remains than suffices to keep the soda in solution ; the soda crystallises out from this liquid as it cools. The soda crystals that form contain almost exactly 63 per cent. of water, which is held fast by the crystals and is known as *water of crystallisation.* Many salts have this property of binding to themselves definite quantities of water of crystallisation.

When soda crystals are exposed to the air for a long time they undergo a visible change, they lose a part of their water of crystallisation, and the crystals fall to powder, as it is only when combined with the water of crystallisation that they exhibit their characteristic crystalline form. The large amount of water of crystallisation in soda crystals would add unnecessarily to the cost of carriage, and for this reason it is customary to manufacture anhydrous carbonate of soda by strongly heating soda crystals until all the water of crystallisation is removed. The product known as *calcined soda* is sent into the market in the form of a white powder.

Carbonate of soda contains no sulphur—that is to say, all the sulphur that was used in the form of sulphuric acid for the purpose of transforming the common salt into sulphate of soda has no part in the finished soda, and so is lost. This sulphur is to be found in the residue that is left when the melted mass has been lixiviated with water. This residue must of course accumulate near the factories, unless these are placed near the sea—as is the case with some English works—and the waste is carried out to sea day by day and discharged there. This *alkali waste* is a great nuisance to the neighbourhood, and gives rise to loud and just complaints. When, for instance, rain falls on the waste, sulphuretted hydrogen, that is the evil-smelling gas that is evolved from rotten eggs, is given off, being derived from the sulphur contained in the albumen of the eggs (cf. p. 62). The rain falling on the heaps of alkali waste also lixiviates these, and the liquid that drains off contains sulphur compounds and poisons all the brooks and springs in the neighbourhood. These and other evils have caused attempts to be made to find some profitable use for alkali waste ; the only way that profit can be made out of the waste is to recover the sulphur. An astounding amount of thought, labour, and money has been spent since about 1840 in attempts to solve this problem.

It is impossible to give an account of the processes that have at last been crowned with success—not to speak of the many processes that were partially successful, but failed on the large scale because the sulphur they produced was more expensive than that which could be purchased in the form of pyrites—inasmuch as to understand these processes requires much chemical knowledge supplemented by an extensive acquaintance with technical details. The problem was finally solved in England about the end of the year 1880 by the invention of a process which turns out chemically pure sulphur. The statement that to set up the plant for working this sulphur recovery process costs about £75,000 will give some notion of the enormous quantities of sulphur that are dealt with in the process and of the complication of the process itself.

At one time the soda industry was dependent on the supply of Sicilian crude sulphur; at a later time the industry was compelled to obtain its sulphuric acid from the sulphur contained in pyrites; and now the same industry has reversed matters, and by turning out the sulphur which it took from pyrites in the form of pure sulphur it has become a powerful rival of the Sicilian sulphur trade.

We have now become acquainted with the broad outlines of the Leblanc soda process, and we have also learnt something of the chief of those bye-industries which have been created by this process. The existence of this process, which has been carried on successfully for something like sixty years, has been jeopardised since about the beginning of the year 1880.

A much simpler method for transforming common salt into soda than that used in the Leblanc process has been known for a long time. The principle of this method, which can easily be carried out in the laboratory, is as follows. The base ammonia combines with a certain quantity of carbonic acid to produce carbonate of ammonia, and it also combines with twice as much carbonic acid to form bicarbonate of ammonia; when a solution of the last named salt is added to a solution of common salt double decomposition occurs, and a precipitate of the comparatively insoluble bicarbonate of soda is produced, while salammoniac (chloride of ammonium) remains in solution.

Bicarbonate of ammonia + sodium chloride = bicarbonate of soda + ammonium chloride.

The process based on this reaction is theoretically extremely simple. The first patent dates from 1838; and we know that soda was made by this process in the years 1855-57 in a French factory, and was sent into the market under the name of *ammonia soda* to distinguish it from soda made by the Leblanc process. But as the ammonia process was given up after a time because it could not compete with the Leblanc process, there must have been difficulties in the way of carrying out the reactions on a manufacturing scale. These difficulties, which are chiefly mechanical, and are due to the stoppage of the pipes by salts that separate during the process, were finally overcome by Solvay, and very large quantities of soda are now manufactured by this method.

The process is carried out somewhat as follows. Ammonia gas is pumped into a solution of common salt, and when sufficient ammonia is present carbonic acid gas is then forced into the solution. Bicarbonate of ammonia is thus formed in the liquid, and by reacting with the sodium chloride this salt produces bicarbonate of soda which separates as a solid.

The common salt required for the process is got from the salt mines [or salt brine is pumped directly from the salt-bearing strata], and the ammonia that is needed comes from the gas works. The large quantities of carbonic acid that the process demands are obtained by calcining chalk in ovens, and the gas that is given off is forced by air-pumps into the brine.

When chalk is calcined in lime kilns it separates into lime and carbonic acid gas; as carbonic acid is also produced by the burning of the carbonaceous fuel used for heating the kilns, the gases given off from these kilns are very rich in carbonic acid, and they are used in many industries, besides soda making, wherein that gas is required.

The bicarbonate of soda obtained in the way described has to be transformed into "*soda*," which is the normal carbonate. To do this it is only necessary to calcine the bicarbonate at a moderate temperature, whereby the second molecule of carbonic acid is driven off.

The liquids drawn off from the bicarbonate of soda contain salammoniac; and as a matter of course ammonia is recovered from these liquids. Ammonia is driven out from its combinations by any base that is stronger than itself; when, therefore, these solutions are boiled with caustic lime, which is produced in the lime kilns of the soda factory along with carbonic acid, ammonia is driven out by the more basic lime. The ammonia obtained in this way is pumped into a fresh lot of brine, and the manufacture goes on uninterruptedly.

The final bye-product of the manufacture is the chloride of calcium produced by boiling the solutions of salammoniac with lime. This solution, or the solid chloride of calcium produced by evaporating this solution, has not yet found any special application, and there is nothing to be done with the large quantities of this substance that accumulate in the ammonia soda works except to run it into the nearest river.

It is evident that the chlorine which is originally brought into the process in the form of chloride of sodium is not used, but is thrown away as chloride of calcium. In the Leblanc process, on the other hand, the chlorine of the common salt is recovered as hydrochloric acid, which, either as it is or when transformed into bleaching powder, etc., has a considerable value.

The two processes for manufacturing soda continue to be practised, but the conditions are unfavourable for the Leblanc process. It costs much more to make soda by the method of Leblanc than by the method of Solvay; but in some places the former process thrives because hydrochloric acid, that used to be the bane of the manufacture, is very much used in these places, and the other soda making process does not produce this acid. But if the problem could be solved—and many attempts have been made—and chlorine or hydrochloric acid could be produced cheaply, either from the chloride of calcium that is now a waste product in the ammonia process, or at some other stage of the manufacture, the Leblanc soda factories would be doomed. There is no sign that this problem is nearer a satisfactory solution now than in past years. But no one can tell what the future may have in store.

The following facts have been established very recently. It is now possible to obtain caustic soda and chlorine—and therefore such salts as chlorate of potash, chloride of lime, and the like—directly from common salt by the aid of electricity (see the end of

Lecture XI.). The fortunate possessors of the patent think they will be able to manufacture such chemicals as those mentioned at a cheaper rate than they can be produced by the Leblanc soda process. If this hope is realised it will be the death blow to the Leblanc process. Experiments with the new process have been made in England on a large scale, and people are also busy with the method in Germany.

These things do not seem to be in keeping with the dicta of moral philosophy which tell us that every worthy piece of work receives its reward. We see here that a good piece of work demolishes another equally good, and that progress is made by the new constantly replacing the old.

After some of the English soda works using the Leblanc process had stopped operations, the others formed themselves into a huge *Alkali Trust* with a capital of about seven millions *sterling*, a fact which shows the ever increasing magnitude of the manufacture of soda in that country.

Although the consumption of soda is very great, and soda has driven potash out of many industries, nevertheless there is still a very considerable demand for potash. The chief source of potash salts is wood ashes. Large quantities are also produced by a process similar to the Leblanc process for making soda, sulphate of potash from Stassfurt salts (see p. 48) being used in place of sulphate of soda. But it is much more difficult to make potash than soda by this method. All attempts to prepare potash on the large scale by the Solvay ammonia method have failed hitherto. Two quite new sources of potash salts have, however, been made available since the middle of this century; these are *molasses* and the *washings of wool.*

Molasses is the name given to the final mother-liquor in the manufacture of sugar (see p. 77). Although means are now known for extracting the sugar from molasses, yet a great deal of this substance is still used for making spirits by fermentation. The residue that is left (see p. 110) when the spirit is distilled off from beetroot molasses has no value as a food, as it contains only the salts that were originally present in the beets and went into solution when the beets were macerated with water (see p. 75). These salts, coming as they do from the soil, are rich in potash; if the molasses residue is evaporated to dryness and calcined the potash salts can be obtained by then lixiviating with water.

The second source of potash salts mentioned above is more remarkable. Factories have been established for washing the crude wool that is brought in large quantities into Europe, chiefly from Australia, Africa, and South America. The grease that is taken out of the wool by the washing accumulates in the wash water, and this grease has been found by experiment to be rich in potash salts; these salts are obtained by evaporating the wash water to dryness, calcining, and extracting with water. Considerable quantities of potash salts are obtained from this source, and the extraction of these salts has become a paying process.

Neither carbonate of potash nor carbonate of soda is directly applicable to the making of *soap*, which is the subject we have now to consider. These compounds do not act upon the fats from which soap is manufactured. The carbonates of potash and soda must be transformed into caustic potash and caustic soda respectively. This is done by the action of caustic lime on solutions of the carbonates in question. Thus

Caustic lime + carbonate of potash = carbonate of lime + caustic potash;
Caustic lime + carbonate of soda = carbonate of lime + caustic soda.

Burnt lime is slaked by water, and the *milk of lime* thus obtained is added to a solution of carbonate of potash or carbonate of soda, and boiled; the carbonate of lime that is formed, being insoluble in water, settles down, and caustic potash, or caustic soda, is found in the liquid. The preparation of caustic soda has formed a part of the business of soda factories since about 1850; *solid caustic* is obtained by evaporating the liquor drawn off from the precipitated carbonate of lime, and this solid caustic is used in soap making.

The caustic soda is dissolved in water, and this caustic lye is boiled with fats, which, as we know, are compounds of glycerin with fatty acids (see p. 21) whereby the decomposition represented in the following scheme occurs.

Compounds of glycerin and fatty acids + alkali = compounds of alkali and fatty acids + glycerin.

Soap is a mixture of compounds of fatty acids with alkali.

We are told by the elder Pliny that the Germans prepared an ointment by boiling ashes with fat; but it was not until about the second century A.D. that this substance began to be used for cleansing purposes, although at that time and for some time afterwards it continued to be employed more as a medicament than a detergent. We know that Marseilles boasted a flourishing soap industry about the year 1000, and that it was not till the fifteenth century that the Venetian factories entered into competition with Marseilles; from that time the art of soap making spread gradually over the world.

The manufacture of soap remained a purely empirical handicraft, as nothing was known of the chemical changes involved in the processes, until, in the early years of the present century, the French chemist Chevreul made known the nature of the fats, showing them to be compounds of glycerin with fatty acids. This discovery threw light on the processes of soap making; and when, in addition to this, the soap-maker was able to use the comparatively cheap caustic soda as well as the more expensive potash, the manufacture of soap began to expand, and this went on until to-day soap has been brought within the reach of even the poorest person.

The fact that the only fats at the disposal of the soap-maker were animal tallow and olive oil gave a certain stability to the soap industry in older times; but the extension of commerce is now constantly bringing new kinds of fat and new oils into the soap factories, and these require special methods of treatment, and demand much consideration on the part of the manufacturer if he is to retain his position in competition with his ever active neighbours.

Every one knows the statement, All misfortunes come from change. This saying comes to our minds in the present instance. But it would be better to say, Every advance comes from change. For we certainly do not share the opinion that it would be a fortunate thing for us to stand still in the old ways of the centuries that are past.

Fat is nowadays a bye-product of many industries; this is true, for instance, of the fat from bones. We have already spoken in some detail of the ways in which bones are most advantageously made use of (see p. 44). The fat of bones is of no value for the purposes we have spoken of, and it is therefore removed before the bones are used. It used to be the custom to boil the bones vigorously with water; the fat was then separated and rose to the surface of the water. But this method did not completely remove the fat.

The method now in use consists in breaking up the bones into suitable pieces, and then extracting with petroleum ether in special apparatus; the whole of the fat is obtained in solution by this process.

The chief difference between soaps made by the use of potash and those made by using soda is that the former are soft soaps while the latter are hard soaps.

The process for making soft soap consists in boiling the cheapest kinds of soluble oils, such as fish oil, hemp oil, or linseed oil with potash lye in iron vessels. If the lye is allowed to act slowly the soap may be taken to be ready when the contents of the vessels have acquired a pasty consistency. Soap made in this way does not dry in the air, but always remains soft. It can bear a good deal of loading—that is, substances may be added to it pretty freely without their presence being shown. For instance, it can take up a considerable quantity of *water glass* (that is, *silicate* *of soda*, to be spoken of later under glass); and solutions of sulphate of potash and other substances are also employed. Such additions are useless so far as the detergent power of the soap is concerned, but they serve to increase the weight of the soap, and as these loading substances are cheaper than soft soap it is possible to sell loaded soap at an extremely low price.

Until a method for making soda was worked out, in the way already described, the only alkali available for making soap was caustic potash got from potashes, and therefore soft soap was the only soap that could be manufactured directly. But the discovery was made at an early stage of the manufacture that the addition of common salt after boiling the fat with caustic potash produced a marked change in the product. The effect of salting is to cause the separation of a liquid which lies beneath the soap and can be drained off, and also to make the soap carry with it much less water and to cause it to separate as a white semi-solid mass which becomes hard when it is cold.

The cause of this change is found in the reaction which takes place between the common salt (chloride of sodium) and the potash salts of the fatty acids, resulting in the production of chloride of potassium and soda salts of the fatty acids. The fatty salts of soda are not able to combine with all the water which comes from the lye; some of this water therefore separates as a liquid underlayer, and this layer also contains in itself the glycerin that has been separated from the fats by the process of saponification, and the chloride of potassium; these two are thus removed in the watery layer. If one salting is not sufficient the process is repeated. The genuine toilet soaps are formed by the solidification of the fatty salts separated by this process. As the salting is never completely effective these toilet soaps always contain some of the fatty salts of potash, that is some non-solidifying soap, and it is this which gives them their pleasant softness. One hundred parts of tallow treated in the way described yield about 160 parts of good soap containing from 10 to 20 per cent. of water.

But the greater part of the soda soaps made at present are made by boiling fats with caustic soda—that is to say, by a process which yields hard soaps directly.

Hard soaps can be loaded as well as soft soaps. If the product of saponification is boiled with water for a long time, and is then let cool, the soap solidifies to a hard mass without the separation of a watery underlayer. Such soap contains about 50 per cent. of water; it is known as *fitted soap*.

High class loaded soda soaps are best prepared with the help of cocoanut oil. The white pulp of the fruit of the cocoa palm, which grows in tropical countries, is dried and exported to Europe, where a fat is extracted amounting to about 68 per cent. of the weight of the substance. This fat melts at about 21° C. [about 70° F.]; it is therefore fairly solid at ordinary temperatures, and because of its consistency it is known as cocoanut butter.

Attempts have been made to prepare a substitute for butter from this substance by removing the more volatile ingredients by passing superheated steam into the liquefied oil, and neutralising the free fatty acids by addition of such a basic body as magnesia. But although the product has been much puffed it has not come into favour, nor has it been found appetising by ordinary mortals.

Soap is not made from cocoanut oil alone, because of the very disagreeable odour which always persists in this oil, but from a mixture of one part of this oil and two parts of palm oil and a little tallow.

The palm oil is derived from the oil-yielding palms that flourish on the west coast of Africa and in Central America. The flesh of the fruit and the seeds of these palms are rich in oil. The fruit is boiled by the natives to obtain the oil, and the seeds, which are very hard, are sent to Europe, where they are pressed. These seeds yield about 40 per cent. of their weight of palm fat, and the residue serves as an excellent oil-cake fodder especially for milk cows (see p. 61).

Cocoanut oil is very easily saponified, and this readiness to undergo saponification belongs also to mixtures which contain this oil. Complete saponification is accomplished by heating to about 80° C. [about 175° F.], which is much under the boiling-point, with concentrated caustic soda lye containing a little carbonate of soda; the whole liquid solidifies on cooling, and the soap is made. Inasmuch as all the water of the lye is enclosed in the soap, as much as from 270 to 300 parts of soap are obtained from 100 parts of the mixture of oils—that is to say, nearly twice the yield that is got from tallow.

Resin soaps are often spoken of nowadays. A good soap, serviceable for ordinary requirements, cannot be made from resins alone—*colophony* is the resin chiefly used—but we have already seen that soap solutions made by boiling resins with soda lye are used for sizing paper (see p. 175). But if soap is being made from tallow or palm oil, and a quantity of resin equal to about half the amount of the fat that would normally be employed is added, in place of fat, to the boiling soap paste, this resin is saponified along with the fat, and a very cheap and very useful resin-fat soap is obtained.

Genuine soaps then are prepared by boiling tallow or other similar fat, or oils, with caustic soda or caustic potash lye. Now we know that there are many other alkalis besides soda and potash, hence there must be other compounds of fatty acids and alkalis besides those that are known as hard soap and soft soap.

The strongest alkali, in the chemical meaning of the term, is slaked lime. Now the compound of lime with the fatty acids that is indicated by theory has been actually prepared. But this compound is insoluble in water; when it is mixed with water it sinks to the bottom as any other insoluble powder would do, and the water does not froth when shaken up, nor has it any of the other properties that belong to a solution of soap. This substance is indeed exceedingly inconvenient in everyday life. Because of its insolubility in water it precipitates whenever an opportunity is given for its formation; if we bring soda soap or potash soap into ordinary water this compound of lime with the fatty acids of the soap is produced. It is well known that all kinds of waters, except distilled water, contain more or less chalk; hence whenever soap is brought into ordinary water used for domestic purposes this lime compound is formed, and so much of the fatty acids of the soap as enters into combination with lime ceases to be available for washing purposes. The more chalk a water contains the more of this lime compound is formed, and therefore the greater is the destruction of soap. For it is only after all the lime has been combined with the fatty acids of the soap that the water can have the properties of a solution of soap and can exert those detergent effects for which we use soap and water.

It is customary, then, in daily life to distinguish between *soft waters* and *hard waters*. The soft waters, such as river water, are poor in chalk, and only a little soap is needed to make these waters lather ; but hard waters, such as spring water, contain much chalk, and they consume a considerable quantity of soap, reacting with it to form lime salts of the fatty acids of the soap, before a lather begins to be produced.

The compounds of lime with the fatty acids that are contained in soaps cannot be used for washing purposes ; but the state of affairs is different when oxide of lead is used as an alkali and fats are boiled with this substance. A compound of lead with the fatty acid is formed—that is to say, a lead soap is produced ; and this compound is of the nature of a *plaster*. Plasters are substances more tenacious and harder than ointments, and they are used, just as ointments are used, as healing agents for external application. Pure lead soaps are used as plasters, and also lead soaps modified by additions of very different sorts of materials. The German sticking plaster, for instance, is a mixture, spread on linen, of 500 parts lead soap, to which, heated to 60° or 80° C. [about 140° to 175° F.], 50 parts of wax are added, and also 50 parts of a mixture of melted dammar resin and colophony, and 5 parts of turpentine. The English sticking plaster is an altogether different preparation. It is made by stretching strips of woven silk cloth on a frame, and brushing over these a solution of the very best glue in dilute spirit until a piece adheres firmly to the hand, after being moistened. The preparation is slightly perfumed with a little gum benzoin, or a similar substance.

LECTURE X.

Glass.—Glass mirrors.—Potash and soda glass.—*Strass*.—Ruby glass.—Milk glass.—Clay.—Bricks.—Mortars.—Glazing.—Pottery.—Stoneware.—Majolica ware.—Porcelain.—Photography.—Lunar caustic.—Chloride, bromide, and iodide of silver.—Daguerreotypes.—Development of the negative.—Talbotypes.—Albumen methods.—Wet collodion processes.—Dry silver bromide emulsion plates.—Platinotypes.—Photography of the spectrum.—Red light.—Orthochromatic plates.—Colour photography.—Chromegelatin.—Pigment printing.—The X rays.

In speaking of the manufacture of soap mention was made of silicate of soda, or water glass, which is a very soluble salt that is used for loading soft soaps. This salt and silicate of potash are the only compounds of silicic acid that are soluble in water. But these salts also become insoluble in water when they are mixed with other silicates and the mixtures are melted. For instance, if silicic acid, potash, and lime are fused together the product contains silicate of potash and silicate of lime, and is insoluble in water. This product is called *glass* when it has been prepared with proper skill and has been brought into such a form as makes it useful to us.

In making glass the practice has long been to melt together silicic acid, potashes (that is, carbonate of potash), and carbonate of lime; the carbonic acid, which is driven out from the melted compounds by the silicic acid, escapes as gas, and there remains a mixture of silicate of potash and silicate of lime.

Silicic acid + carbonate of potash = silicate of potash + carbonic acid.
Silicic acid + carbonate of lime = silicate of lime + carbonic acid.

The salts of silicic acid are called *silicates* in chemical nomenclature; and glass may be defined as a mixture of several silicates melted together. This definition admits of a very wide and comprehensive interpretation, and it is not necessary to confine oneself to silicic acid, potash, and carbonate of lime; as a matter of fact, in glass-making sometimes one and sometimes another of these constituents is replaced wholly or in part by another acid or by other bases which experience has proved to be suitable for the objects of the manufacture. We shall have to speak of the most important of these materials.

A very high temperature is required for melting the materials that have been mentioned. This fact is sufficient of itself to relegate Pliny's story of the discovery of glass to the domain of fable. According to that story certain Phœnician merchants had made a fire under a vessel which they had supported on lumps of "*soda*,"* the soda melted by the heat, and coming into contact with sand (that is, with silicic acid), and the other necessary materials on the ground, produced glass. Now such a fire as that described in Pliny's story could not have been hot enough to melt glass. At the same time we need not be astonished at finding glass objects in very ancient tombs, since we know that the art of smelting metals was practised from very early times and this art requires the maintenance of high temperatures.

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* The term used by Pliny is generally translated *soda*; but it is certain that Pliny was not acquainted with the substance that we now call by this name.

Glass was exceedingly costly in the old days. The most famous glass factory of the Middle Ages was at Murano near Venice, and this factory, after nearly collapsing, has been revived in our own times. Glass is manufactured to-day in every country where the cost of labour is not too great.

The employment of glass in windows, for which purpose nothing can replace it, came in very gradually because of the high price of the material. Although the windows of churches had been filled with glass at a much earlier period, yet it was not until about the fourteenth century that glass began to be used in the windows of the private houses of the rich, and several centuries passed before it had completely taken the place of the oiled paper and the solid window shutters of that period. The extraordinary gladness wherewith the German singers of the early Middle Ages greeted the return of spring may have had some connection with these window coverings. Men escaped in spring from the wretchedness of spending the long days of winter in half darkened rooms lighted by the feeble glimmer of a chimney fire.

Glass-making then requires silicic acid. This is ready to hand either in the form of sand, which is silicic acid, or in the form of quartz, which is crystallised silicic acid. The purer the raw material the better is the result. The presence of iron is prejudicial, for the silicate of iron which would be formed in the manufacture is very dark coloured; and it is the presence of this salt in cheap glass that gives that glass its dark colour. This colour is also sometimes given to wine glasses. In older times all window glass was greenish, because sand is seldom found quite free from iron; but the modern means of transport enable pure sand to be sent anywhere.

In a very few cases silicic acid is partially replaced by the much more expensive *boric acid.* This acid produces a very lustrous glass which is especially useful in making certain optical instruments.

As every variety of glass must contain either potash or soda only potash glass was manufactured in older times because only potash, in the form of potashes, was available. The use of potashes was also connected with the fact that, in Germany at any rate, glass factories were generally located in forests, for not only did the forests provide fuel for heating the furnaces, but the ashes of the burnt wood provided potashes, and if more potashes was required it could easily be obtained on the spot.

After a time soda began to be used as a substitute for potash; but when the manufacture of soda was established a cheaper substitute for potash than soda was forthcoming. We know that the first stage in making soda by Leblanc's process is the conversion of common salt into sulphate of soda. Now sulphate of soda may be used in glass-making in place of soda; it is only necessary to mix the sulphate of soda with coal, or charcoal, in order that silicate of soda may be formed in the reaction with silicic acid.*

Carbonate of lime is generally used in the form of chalk, because chalk is easily obtained free from obnoxious ingredients, especially free, or nearly free, from iron; some specimens of chalk are indeed perfectly pure carbonate of lime. A whole series of other bases may be used in making glass in place of lime; lead oxide is one of those that is often employed (for more details see later).

Finally, the glass works melt up old glass with the materials for making new, and for this reason most of the broken glass finds its way back to the furnaces.

When the materials for making glass have been thoroughly mixed by machinery they are melted together in large pots. It is of course desired to get a high temperature in the melting ovens with the minimum consumption of fuel, and for this reason these ovens are generally worked nowadays with regenerative gas furnaces. We shall consider the arrangement of these furnaces when we are dealing with the iron industry.

The glass-blower removes some of the molten glass from the furnace on the end of his rod, and by blowing into the other end of this rod he is able to cause the glass to assume almost any shape he pleases; if the object to be made is very complicated the aid of a second workman is needed. The glass-blower's rod is nothing but a piece of metal tube covered with wood in the middle so that it may be handled when hot. Ordinary bottles are now made by machines as well as by blowing. When the glass has been shaped to the desired form it is brought, while still hot, into the annealing oven, where the process of cooling goes on very slowly over a period of a few days; if this were not done the glass would be so brittle as to be practically useless. It should be remarked that glass for windows is made in the way described. The workman blows as large an oblong cylinder as possible; this is cut off by shears, and, being still very soft, is flattened out, and then put into the annealing oven, from which it comes as a finished pane.

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* The reaction proceeds in this way: while the silicic acid combines with the soda the coal reacts with the sulphuric acid, which is the other constituent of sulphate of soda, and at the high temperature of the furnace the coal robs the sulphuric acid of part of its oxygen forming monoxide of carbon, which escapes as a gas, and leaving sulphurous acid, which being also a gas passes off (see the reverse process described on p. 190). Hence none of the sulphur that was originally present in the sulphate of soda employed remains in the finished glass.

The discovery, made in the seventeenth century, that glass can be cast was of great importance. For this purpose molten glass is poured on a metal table, of sufficient size, furnished with a raised edge. All those large panes of plate glass that we see in shops nowadays are made by cutting sheets of cast glass. As these sheets can be cast of considerable thickness they can be made strong enough to be used for letting into floorings to give light to rooms beneath. When used for this purpose the glass is of course not ground.

Plate glass is also used for making the glass mirrors that have completely driven out the metal mirrors of former times. Before glass mirrors were invented finely polished plates of silver, or of a very white alloy made of two parts of copper and one part of tin, were used as mirrors. But these metallic mirrors were very inconvenient because of the sensitiveness of the surfaces, especially the surface of silver which is so easily blackened. As the reflecting surfaces of glass mirrors are protected by glass these mirrors are entirely unaffected by outside influences.

In order to make a plate of glass into a mirror a sheet of *tinfoil*—that is, tin beaten very thin—over which mercury has been poured is laid on one surface of the glass. The mercury dissolves the tin forming with it what is called an *amalgam* ; and this amalgam has two properties—it reflects light admirably and it adheres very firmly to glass. The excess of mercury is drained away by gradually raising the plate from its original horizontal position into a sloping position ; after about four weeks the mirror is ready for use.

Mirrors made in this way leave hardly anything to be desired. But the process is extremely risky to the workmen, as they are constantly exposed to the danger of mercury poisoning by the fumes of this metal ; for mercury volatilises slightly even at the temperature of an ordinary room.

Chemists have long been acquainted with another method for making mirrors besides that wherein tin amalgam is used as the reflecting surface ; in that other method silver deposited on the glass forms the reflecting surface that is required. The suggestion to use this method on the large scale came from England.

The foundation of the process—the exact chemical reactions cannot be made clear in this place—is the fact that it is possible to prepare solutions of silver from which the metal can be again precipitated as such by the addition of certain reagents. If the conditions are properly arranged the silver is not thrown down rapidly as a powder, but it is precipitated very gradually in the form of an extremely lustrous, mirror-like coating on the sides of the vessel. In applying this process to silvering a plate of glass the properly chosen mixture is poured on to the side to be silvered, and after a time the mirror of silver is formed. As silver is the whitest of all the metals these mirrors are superior to all others, and a mirror made by using mercury seems dark when placed beside one made by the silvering method. The description of the preparation of these mirrors shows that the manufacture is quite harmless to the workpeople. Nor is the method expensive, although silver is the metal used. Only about 2½ grams of the metal are deposited on a square metre of surface [about 38 grains on 10¾ square feet], and this quantity of silver costs to-day only about threepence.

The statement always holds good that potash glass is much harder to melt than soda glass. For this reason apparatus is made of potash glass especially for the use of chemists and physicists. Very great advances have been made recently in preparing the glass vessels in which so many substances are boiled in chemical laboratories; these advances are based on turning to the best account our knowledge of the chemical and physical properties of glass. The vessels must be very thin in order that they may be quickly heated equally in every part; nevertheless the frangibility of them is not great when they are handled by people who have got accustomed to working with them. It has always been necessary to heat glass dishes very carefully; but glass apparatus is now to be had in which liquids may be heated to about 180° to 200° C. [about 350° to 390° F.], and which may then be plunged into cold water without breaking. Such an improvement as this was hardly to be expected.

The most easily melted glass is that wherein lead oxide replaces most of the lime of ordinary glass. This glass is extremely easily manipulated, and those prettily ornamented plates, dishes, *épergnes*, and the like that are now much used are made by casting this kind of glass in moulds. Moulded glass does not of course show the sharp edges that characterise cut glass; but the price of the former is very much less than that of cut glass ware.

The name *strass* (or *paste*) is given to the glass obtained by melting a mixture of silicic acid, potashes, and lead oxide without the addition of any lime; this product is a true double silicate of potash and lead. *Strass* is extremely lustrous; indeed it sparkles so that it is used for counterfeiting various gems. If such artificial gems are skilfully cut and polished it is impossible to distinguish them by the eye alone from the genuine stones. But as lead glass is soft the artificial gems soon get scratched by handling, and in this respect they differ entirely from the natural precious stones which are quite indestructible. The artificial gems are of course coloured to imitate the different genuine gems.

The colouring of glass is done by adding suitable substances to the glass when it is molten; the addition of cobalt, for instance, produces a blue colour. The most beautifully coloured glass is that known as *ruby glass*, the colouring matter of which is gold added in the form of a suitable compound called *gold purple*. The quantity of gold used is extremely small. This glass is chiefly used for making delicate table ornaments and things of that character.

Finally, we must look for a moment at *milk glass*. This is obtained by adding phosphate of lime, generally in the form of bone ash (see p. 45), to the molten glass. As the mass cools the phosphate of lime separates, and the desired opacity is thus given to the glass. Some other substances produce the same effect as phosphate of lime, such for instance as *cryolite*, which is a mineral from Greenland containing alumina and a compound of sodium and fluorine, and is quite free from iron. The milk glass made by using cryolite is especially suitable for the shades of lamps, because the flame of the lamp cannot be seen through this glass, whereas the flame appears blood-red through glass manufactured by the older processes.

We come now to *porcelain* and *pottery*.

There are certain kinds of earth found in many places which when stirred up with water form a tenacious mass that can be moulded and kneaded. Such earths are called *clay*, and special names are given to different clays in accordance with their compositions and the uses to which they are put. The commonest kind of clay generally contains a good deal of sand and is coloured brownish yellow by iron. Bricks are made by working this clay into oblong pieces. When such bricks have been dried in the air they are not very durable; indeed a shower suffices to cause them to run. Still they often serve to fill in the spaces between the timbers of framed buildings. But as fewer of such buildings are constructed nowadays, because of their liability to catch fire, air-dried bricks are gradually going out of use.

These air-dried clay blocks are rendered durable and stone-like, they are changed into true bricks, by being burnt. The custom used to be to build up alternate layers of unburnt bricks and turf, wood, or coal into heaps, to cover these outside with clay, so that when the combustible material was set fire to the bricks got very strongly heated. But this method led to what is called *sintering*—that is to say, the easily fusible parts of the clay became nearly liquid, and as this semi-liquid matter cooled it bound the whole heap of bricks into one mass. Inasmuch as the iron compounds in the clay are changed into the red oxide of iron during the burning the burnt bricks are red. The practice to-day is to burn bricks in what is called a ring oven, whereby a much greater effect is obtained from the materials used for heating.

It is advisable to say something now regarding *mortars*, as no other opportunity will occur for dealing with the subject. The mortar that is generally used in brick buildings is a mixture of slaked lime and sand. We know that when limestone is strongly heated it separates into its constituents caustic lime and carbonic acid (cf. p. 201). Caustic lime is a solid body which is nearly as hard as unburnt limestone; but it possesses the remarkable property of crumbling to powder when it is brought into contact with water. Burnt lime chemically considered is the oxide of the metal calcium, and this oxide has a great readiness to combine with water. A great deal of heat is produced in this process, and the oxide of calcium is changed into hydroxide of calcium, which is slaked lime. Slaked lime may be made into a kind of paste with water, and a mixture of this with sand forms ordinary mortar. The mortar hardens completely between the bricks; in doing this it combines with the carbonic acid of the air and again forms carbonate of lime. The custom of burning baskets of coke in new buildings arises from this fact; carbonic acid is produced, and this hastens the setting of the mortar. In the course of centuries the sand in the mortar, which chemically looked at is silicic acid, also takes a part in the setting process by gradually forming silicate of lime, which is an extremely hard substance. It is for this reason that old brick buildings are so very solid; it was not the ancients who made such durable mortars, it is age that has done it.

Such mortar as has been described cannot harden except by exposure to the air; it cannot, therefore, be employed in building under water. But if certain additions are made to the constituents of mortar—for instance, a large quantity of silicic acid and alumina—the mixture has the property of setting to a hard mass under water. Mortars of this kind are called *cements.* Such mortars were known in ancient times; they were probably found out accidentally, as we know that limestones are often found containing large quantities of alumina, and such limestones form hydraulic mortars.

To meet the enormous demand for cements nowadays limestone is mixed with alumina and other similar substances before it is burnt; and in this way any wished for quantity of cement can be manufactured, and the supply is independent of the discovery of natural limestones containing alumina.

The main constituent of all clays, to which we now return, in a chemical sense, is silicate of alumina. Pure silicate of alumina is infusible in an open furnace; but its fusibility is much increased by the admixture of sand (silicic acid), lime, potash, and oxide of iron. We know indeed that silicates of potash and lime, and also silicate of iron, can be melted to a glass. These constituents of clay melt when bricks are burnt, and so produce hard and compact bricks.

If a specimen of clay is very poor in these constituents that clay will withstand the fire; the most fire-resisting bricks are made from such clays, and these bricks are used for erecting fireproof buildings and for other similar purposes. These bricks are generally called *fire-clay bricks.*

The plasticity of clay allows of the modelling in it of the most diverse objects, so that it is not only such simple things as bricks that are made of this material.

It is easy to produce convex vessels, and vessels of other forms having circular cross sections, by working clay on a rapidly rotating wheel. The potter's wheel has been known from very ancient times; indeed it has been in use among some peoples—the Chinese, for instance—since times earlier than those of which any written records have come down to us.

If a vessel made on the potter's wheel is baked it comes out of the oven porous like a brick, and such a vessel can scarcely be used for any length of time except as a flower-pot. If a liquid is poured into a pot of baked clay the liquid soaks into and perhaps through the walls of the pot, and the vessel cannot be properly cleansed. To remedy this state of affairs articles made of baked clay are *glazed*—that is, they are covered with a glass.

We know that lead glass is the most fusible kind of glass (see p. 222). The cheapest way of glazing pottery is therefore to mix clay with any suitable naturally occurring lead compound, to powder this mixture finely, and to cover the article to be glazed with the fine powder that deposits after the mixture has been stirred up with water. When the pottery is then placed in the oven, silicate of lead is formed by the combination of the silicic acid of the clay with lead, and being melted runs over the surface of the pots and forms a glaze thereon, so that the pots are no longer porous; after a single firing the process is finished. *Galena* is the lead compound most commonly used for glazing pottery; it consists of lead and sulphur, and is found native in many parts of the world. Vessels glazed in this way cannot be used for cooking, because acid-containing foods, such as those prepared with vinegar, dissolve some of the lead, and lead is poisonous. The sale of kitchen utensils glazed with lead glaze is therefore nowadays forbidden by law.

Attempts have been made in recent times so to alter the composition of these glazes as to insure that the whole of the lead is so firmly combined with other substances after firing that none of it can be dissolved by acid-containing foods, for all cooked dishes are acid in the strict chemical meaning of the term. These attempts have met with success, especially in Bavaria.

Stoneware is a much more durable material than ordinary pottery. The clay used for making stoneware is of such a nature that it melts superficially at a moderately high temperature, and on cooling forms a hard mass which is quite impervious to liquids. Articles prepared in this way, such as the cheap grey or brownish bottles in which natural seltzer water is sent out [in Germany], do not require to be glazed to make them impermeable by water.

But another very simple method of glazing, which gives a more agreeable and more lustrous surface, is also practised with all kinds of stoneware goods that are brought into the market. When the oven wherein the goods have been baked has been fully heated some common salt is shaken into the fire, and the draught is shut off for a time. The oven gets filled with the vapour of salt, for common salt is not very difficult to vaporise. Now we know that common salt is a compound of sodium and chlorine; the sodium coming into contact with the silicic acid of the clay on the surface of the vessels forms silicate of sodium, and this combined with other silicates—for clay consists essentially of silicates—forms a glass. To glaze the ordinary cheap stoneware goods it is then sufficient to throw common salt into the oven, and the entire operation requires only a single firing.

Genuine stoneware goods, which differ from pottery in that they are twice fired, are made by selecting a very pure clay, free from iron, and putting the goods back into the oven after they have been once fired; such goods are quite white, and the glaze they acquire is also white. Such stoneware hardly differs externally from porcelain; but the glaze, which has been produced at a lower temperature than the glaze on porcelain, soon scratches when the stoneware is used, and becomes covered with fine cracks, with the result that the vessels cannot be thoroughly cleaned and do not look well; and, indeed, stoneware dishes are not pleasant for eating off for this reason.

The temperature whereat the glaze is burnt into stoneware is not very high, and the custom is to add some borax and some oxide of lead in order to make a glaze that is sufficiently fusible. By properly choosing the mixture of lead oxide and borax the lead becomes so closely combined that acids have no solvent action upon it.

Stoneware vessels become thoroughly hard and durable by the first firing, as this is sufficient to bind the whole mass completely together. It is not necessary that the material should run again while the glaze is being burnt in by the second firing; and there is therefore no danger, as there is in the case of porcelain (see forward), of the vessels getting misshapen and losing their proper form during this process. Hence—and in this these goods differ from porcelain (which see)—generally speaking only three depressions in the surface glaze are noticeable on the bottom of a piece of stoneware, which depressions mark the places where the plate, for instance, was supported during the burning in of the glaze.

Fayence should be spoken of in connection with stoneware. The name of this kind of clay ware is derived from the Italian town Faenza, where the ware was first manufactured. Another name for the same kind of ware is *majolica*, from the island of Majorca, where goods of this description were manufactured in large quantities in olden times.

Fayence requires a very easily worked, plastic clay, in order that the objects—such as dishes, plates, etc.—may be properly fashioned, for it is chiefly for carrying out ornamentations in relief that this ware is used. Anything made in *fayence* is pretty sharply baked; this ware is therefore fairly hard; but as the clay is very fire-resisting, the objects run only slightly in the ovens, and their outlines remain very sharp. On the other hand, we know that a clay which has run but slightly in the fire is porous; hence if *fayence ware* is to be impermeable by water it must be glazed after it has been made. For this reason, when the ware has been once fired it is covered with some glazing material, and is again passed through the fire. Very various effects are obtained by selecting materials that produce either opaque white glazes or coloured glazes. The white opaque glazes are generally obtained by mixing oxide of tin with the constituents of the ordinary glazes.

We have now to consider the most perfect of all clay wares—namely, porcelain.

Porcelain possesses many of the valuable properties of glass in a more marked degree even than glass itself. It is harder, and bears changes of temperature without cracking better, than glass. On the other hand, porcelain cannot be worked into so many shapes as glass; and one has to be content with the pure whiteness of porcelain in place of the transparency of glass.

Porcelain has been known in China and Japan for a very long time. It was discovered in Europe by the Saxon adept Böttcher in 1703. At first he was able to make it only with a brown colour; but in 1710 he succeeded in preparing pure white porcelain vessels, and these have continued to be made since that year in Meissen.

As porcelain must be pure white, and as it must be fired at the highest possible temperature in order to bring out its excellent qualities, only such clays as are quite free from iron and contain no fusible materials can be used in the manufacture. Clay suitable for making porcelain is called *kaolin*; such clay is not very common. This clay is purified by shaking it with a large quantity of water, whereby the heavier and coarser particles sink to the bottom, while the fine particles remain suspended in the water. The turbid water is poured off from the sediment into another vessel, where it is allowed to settle. The fine clay that is thus obtained will scarcely vitrify superficially in the furnace, and it is therefore necessary to add some flux to it before shaping it into vessels which are to be baked. The flux which is used for this purpose is very finely ground and washed *potash felspar*, a mineral found in nature which melts and runs to a glass at a very high temperature. The felspars are double compounds of silicate of alumina with silicate of potash or soda; they contain also some silicate of lime.

Vessels formed of a mixture of washed kaolin and felspar shrink so much when they are fired that they very often crack; but this difficulty is overcome by adding silicic acid to the other materials. Silicic acid is obtained of sufficient purity for this purpose by finely grinding and washing quartz, fireclay, or sand (see p. 231). The mixture of these three materials, to which some manufacturers add a fourth material containing lime, is shaped, like pottery, on the wheel, and the vessels, after being dried (whereupon they become very fragile), are heated in a furnace to a strong red heat, at which temperature they shrink and become compact and fairly hard.

The porcelain that is prepared in this way finds only one application; it is used for the porous cells of galvanic batteries. If a liquid is placed in a pot made of this unglazed porcelain, and the pot is placed in another liquid, the two liquids pass through the walls of the pot and come into contact, and yet they do not mix, in the ordinary sense of the word *mix*; and these are the conditions required for producing an electric current.

Porcelain made as described must now be glazed. The glaze used for porcelain, unlike that employed for other kinds of clayware, is extremely infusible; it forms a true glass, which spreads over the surface of the finished product. The glaze consists of the porcelain material itself, with the addition of some more fusible substance, which makes the melting of the whole possible. The more fusible substance is alkali and lime, the former being supplied by increasing the quantity of felspar.

The finely powdered and washed glazing substance is stirred up with water to a thin paste, and the burnt porcelain is dipped into this, so that a sufficient quantity of the paste adheres to the surface of the porcelain. The glazing paste must be brushed off those parts of the porcelain vessel which will come into contact with the supports whereon the vessel is to rest in the oven, otherwise the vessel will be fused to the supports by the melting of the glaze. It is for this reason that we always notice a raised rim on the bottom of a porcelain plate, for instance, while the bottom of a glass dish is flat. Instead of removing the glaze from the whole bottom of the plate it is only necessary to remove it from the rim. The unglazed parts are rough, and get gradually dirty, because dirt slowly soaks into the pores and cannot be removed by rubbing. It is possible to distinguish genuine porcelain at a glance by the presence of this unglazed rim, for such a rim is never found on the under-surface of even the best stoneware vessels (see p. 229).

In order to melt the glaze porcelain goods are placed in the furnace a second time, and the temperature is raised to a point much higher than that at which stoneware is fired.

We know that stoneware acquires its proper hardness by a single firing, and that the hardness is not increased by the process of burning in the glaze. It is otherwise with porcelain; the product of the first firing, known as "biscuit," is fairly hard and compact, but it is only when it has been fired a second time at a very high temperature that it becomes completely vitrified. The second firing is needed to produce that hard mass, with which the glaze is, so to say, interfused, which is able in so marked a way to resist all external influences. On the other hand, the porcelain gets so soft at this high temperature that unless each piece is supported at many places on its under-surface it is drawn quite out of shape by its own weight.

The course of the firing is regulated by taking out single trial pieces from time to time. As the glaze gradually melts it gets smoother and more lustrous; and when it is seen that the biscuit is sufficiently glazed by the transparency of the whole mass the fire is withdrawn, and the oven and its contents are allowed to cool slowly.

Unglazed porcelain may of course be subjected to the same sharp firing as that by which the glaze is burnt in. If this is done the whole shrinks so much that it loses its porousness; but the surface remains somewhat rough, and looks dull. Such ware is called *biscuit porcelain.* It is used for making busts, statues, and similar objects which would be spoilt by the lustre of a glazed surface.

As regards the *painting of porcelain,* two methods are adopted; the painting is done under, or upon, the glaze.

For painting under the glaze—that is, for painting the strongly heated porcelain—only those metallic oxides can be used—and there are but few of them—which will withstand the very high temperature of the second firing. One has cobalt oxide for blues, chromium oxide for greens, and oxide of uranium (one of the rare elements) for black.

The advantage of this method of painting is that the colours are indestructible; because, as they are protected by the glaze, they can be destroyed only by breaking the porcelain itself. While the choice of colours for painting under the glaze is rather limited, any wished for shade of colour may be obtained when the painting is done on the glaze. Hence any oil painting may be copied on porcelain. This art of porcelain painting has been cultivated chiefly at Sèvres.

The proper colours, which consist, as one would suppose, chiefly of metallic oxides, are mixed with some material that readily melts to a colourless glaze—lead oxide, as we might suppose, is much used—and, after being mixed with oil, are painted on to the porcelain; and the painting is fused firmly on to the surface by heating the piece in a muffle furnace.*

The gilding and ornamenting in gold of porcelain, that were so much used in older times, were carried out in a precisely similar way. The gold, which was burnt in with a fusible substance, was dull when it came from the furnace, and required to be polished in order to make its lustre apparent. A gilding liquid was, however, discovered in 1830—the gold being first of all dissolved in *aqua regia* (see forward, under *gold*)—which could be painted on to the porcelain, under proper conditions, and which, after burning, produced a lustrous gold-coloured effect.

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* A muffle is a kind of box made of fireclay which is heated by a fire playing around it in such a way that the contents of the muffle do not come into contact with the smoke nor with the gases produced by the fire.

We cannot well enter upon an explanation of the phenomena that come into play in *photography*, which is the subject we now turn to, without assuming a certain amount of preliminary knowledge, because the phenomena in question rest on very complicated chemical occurrences.

In this, as in other similar cases, we shall succeed best by making the historical development of the subject the basis of our treatment. By doing this we see the gradual perfecting of the subject, and we have the opportunity of passing rapidly in our own minds through the most important stages of thought which have brought the art to the high position it occupies at present.

Silver dissolves easily in nitric acid to form a clear colourless liquid. When this solution is evaporated a white salt is obtained. This salt is called *nitrate of silver*; it is also often known as *lunar caustic.*

Anything that is rubbed with this salt soon becomes black when exposed to daylight. The human skin, for instance, is blackened by it, and lunar caustic is often used in this way as a cautery. If a solution of this salt is thickened with gum, and letters are written with this liquid, the letters come out black after a little time. Such writing can scarcely be removed, certainly not by washing; a solution of this salt therefore serves as an indelible ink. The reason of this appearance is that nitrate of silver is very ready to decompose into its two constituents—the decomposition is, indeed, effected by exposing the salt to daylight—and in this decomposition the metal silver separates as an extremely finely divided black powder.

This property of the salt has been known for a long time; but it cannot be made use of for obtaining pictures, because the decomposition is much too slow for this purpose.

The preparation of pictures was first accomplished by using certain salts of silver which are much more quickly changed by light than the nitrate is. And the three salts that have been most used in photography are the *chloride*, the *bromide*, and the *iodide of silver*. These three are all easily prepared. As these salts are quite insoluble in water, they are thrown down when chloride of sodium (common salt), bromide of potassium, and iodide of potassium, respectively, are added to a solution of lunar caustic. In the case of common salt, for instance, chloride of silver and nitrate of sodium are produced; thus

Nitrate of silver + chloride of sodium = chloride of silver + nitrate of sodium.

Nitrate of sodium is known to us as a salt that is very easily soluble in water (see p. 52); hence it remains dissolved in the water in the foregoing reaction, and therefore the chloride of silver can be completely freed from nitrate of sodium by washing with water.

Chloride of silver has been known for long; bromide and iodide of silver have been known since the first quarter of the present century, at which time bromine and iodine were discovered. We have already spoken of the chief sources whence these elements come into commerce (see pp. 49 and 53).

The alchemists made great use of chloride of silver.

It is very sensitive to light, for immediately it is exposed thereto its pure white colour begins to change to violet, and this darkens until finally the colour becomes black. A physician of Halle named Schultze was the first to employ this salt, in 1727, for producing pictures. He laid letters cut out of paper on a freshly made precipitate of chloride of silver. Only the exposed parts became darkened, and on removing the paper the letters appeared white on a dark background; but in a short time the letters also became black, owing to the action of the light. All one can say of this experiment is that it furnished an interesting observation but that it was not of any practical utility.

It was not until a hundred and twelve years after this that Talbot, in 1839, obtained actual pictures by using chloride of silver. His procedure was as follows. He dipped paper into a solution of common salt, and then brushed a solution of nitrate of silver over this paper. The paper now contained chloride of silver. On the paper prepared in this way he laid a transparent drawing, and exposed the whole to sunlight. The chloride of silver darkened the most in those parts where the greatest amount of light was able to penetrate through the transparent drawing. Had Talbot now removed the drawing the light would of course have darkened the whole of the paper—that is, Talbot would not have advanced on what had been done by Schultze. But the great improvement made by Talbot was that he found out a method for binding, or fixing, the picture which had been formed. He took the sensitive paper, whereon the sun had produced an image of the drawing, into a darkened room, and there placed it in a boiling solution of common salt. Now chloride of silver dissolves in a boiling solution of salt. The unchanged chloride of silver left on the paper was thus removed, and the drawing remained imprinted on the paper, inasmuch as chloride of silver which has been blackened by sunlight is so chemically changed that it is not dissolved by a solution of common salt.

A consideration of what has been said will show that the picture obtained in the way described must be a negative copy of the original drawing, for the dark parts of the drawing let less light through them than the lighter parts. The chloride of silver that was covered by the darkest parts of the drawing remained quite unchanged, and was therefore removed by the treatment with salt solution, so that these parts appeared white, or nearly white. But Talbot now laid this negative on paper made sensitive by chloride of silver, and in this way he obtained an accurate copy of the original drawing.

Talbot's process was evidently nothing but a photographic method of multiplying the original drawing; but Daguerre, also towards the end of the thirties, brought to completion a method, which had already been investigated by Niépce, for obtaining the first picture by means of photography. To get delineations of objects directly he made use of the *camera obscura*, an apparatus by which pictures of objects placed in front of the instrument are produced, by the use of lenses, at a definite spot where a plate of milk glass has been placed for the purpose of focussing the picture. In place of the plate of milk glass, by the help of which the apparatus was focussed, Daguerre put a plate of silver on which some iodide of silver had been formed by the action of vapour of iodine. A picture appeared on this plate after the action of light had been allowed to continue for about an hour; but he had the greatest difficulty in fixing the picture, and it was an accident which first helped him to get over this difficulty. He noticed that when a plate which had been exposed to light for a short time only was brought into the vapour of mercury most of the mercury was deposited on those parts of the plate which had been most illuminated, and the picture stood out, so to say, in lustrous mercury. Hence comes what seems to us nowadays the very remarkable appearance of those old *daguerreotypes*, as pictures of this kind were called, which are still to be found in many families.

This discovery made it possible to get photographic representations of living sitters. To obtain the likeness of a person all that was now necessary was that the sitter should remain still for a short time; and to-day people can be photographed when in rapid motion.

The part of Daguerre's discovery that must always be of importance is the following. Although the human eye is unable to perceive any change in a sensitive plate that has been exposed for a short time in the *camera obscura*, nevertheless the chemical action of the rays of light has brought about a decomposition of the silver compounds on the plate, and in order to develop a negative picture from such a plate it is not necessary to continue the exposure until the decomposition is completed, but it is sufficient to treat the plate with a suitable reagent, such as vapour of mercury, which is the only reagent of this kind we have as yet become acquainted with.

Attempts began to be made at once to find a substitute for the expensive silver plates of the daguerreotype process, and Talbot was successful in using his sensitised paper in the *camera obscura.* He sensitised his paper with iodide of silver in place of chloride of silver by drawing it through a solution of iodide of potassium after it had been soaked in a silver solution. The iodide of silver paper, however, turned out not to be sufficiently sensitive for the camera; and it was found that an excellent negative of the object to be photographed, with those parts darkest where most light had fallen, could be obtained by dipping the paper after exposure in a mixture of gallic acid and solution of silver.

Talbot now made use of a solution of *hyposulphite of soda,* a salt discovered in 1840 by Herschel, for dissolving the unchanged iodide of silver that remained on the paper after exposure; this salt dissolves chloride of silver, as well as bromide and iodide of silver, very easily in the cold, and it is now always employed for the purpose for which Talbot used it. But the roughness of even the best paper made itself unpleasantly apparent in Talbot's process, and it seemed as if the pictures produced by Daguerre's method on polished silver plates would gain the victory. Matters were, however, altered by Niépce's introduction into photography of solutions of albumen. If iodide of potassium is added to a solution of albumen, and this liquid is poured on to glass plates, which are then dried, and afterwards dipped into a solution of nitrate of silver, a film of albumen is formed on the glass, and this film is sensitive to light because of the iodide of silver which it contains; moreover this film has none of the roughness of paper, and it is capable of yielding excellent pictures.

The pictures produced in the *camera obscura* are negatives, and they must therefore be transferred to sensitised paper, as was originally done by Talbot. From this time onwards the paper to which the negative was to be transferred was covered with a sensitised film of albumen, and very finished results were obtained because of the smoothness of the surface and the consequent brilliancy of the picture produced thereon. But solutions of albumen have an unpleasant readiness to putrefy; this led to the substitution of collodion for albumen, as recommended by Fry. *Collodion* * is a solution of nitrated cotton wool, that is guncotton (see p. 130), in a mixture of ether and alcohol.

The invisible change that is brought about by a brief exposure to light, which Daguerre had succeeded in fixing by means of vapour of mercury, must and can, as we have already mentioned, be fixed on those plates which are used in place of the silver plates of Daguerre. The substances that are employed for doing this are classed together under the name of *developers*. The developers that were used in the earlier days of photography were *ferrous sulphate* (commonly known as *green vitriol*) and *pyrogallic acid.*

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* This substance was first employed, by Maynard, as a glue: hence the name collodion, from κόλλη = glue.

All sorts of chemical substances have been tried from time to time; of these *hydroquinone* has been found to answer especially well, and this body is now more used than any other developer.

In the collodion process, which we shall now consider, the collodion film is mixed with bromide and iodide of potassium and is then dipped into a solution of nitrate of silver, and the wet plate, which contains both bromide and iodide of silver along with some adhering nitrate of silver, is exposed in the camera. If the plate is brought into a solution of green vitriol or pyrogallic acid after exposure, this reagent reduces the excess of silver nitrate to silver, but it does not act on the bromide or iodide of silver on the plate. The silver which is thus separated from the nitrate of silver as a fine powder deposits itself on those parts of the plate which have been exposed to light, in proportion to the amount of light that reached the different parts, just as the vapour of mercury did in the daguerreotyping process. The result of this procedure, which is conducted in the dark chamber, is that the negative becomes visible. The fixation of the negative, which at this stage appears quite black when brought into the light, is brought about by immersing it in a solution of hyposulphite of soda, which dissolves and so removes the remaining bromide and iodide of silver that had caused the complete blackening of the negative. The process may be called an acid process in the chemical sense inasmuch as pyrogallic acid is employed. Attempts were made to prepare in this way dry plates which might be stored and used at any time, but without success.

In 1860 Russell found that the effect of light on the precipitate of silver bromide and iodide on the plate contained in the *camera obscura* could be made visible without the presence on the plate of any excess of silver nitrate. If the excess of silver nitrate is thoroughly washed away from the wet plate by a large quantity of water, and the plate, after exposure, is immersed in an alkaline solution of pyrogallic acid (that is, in a solution prepared by adding alkali to the pyrogallic solution used in the older process), the alkaline pyrogallate acts upon the bromide and iodide of silver—this we know the solution without addition of alkali could not do—in proportion to the amount of light that has fallen upon the plate, and a picture is produced. This process is then an alkaline process (see note, p. 183).

It was soon found that alkaline pyrogallate solution acts much better on bromide than on iodide of silver; and it is for this reason that bromide of silver has become so important in photography.

Maddox in 1871 recommended the employment of gelatin in place of collodion; but the true discoverer of the gelatin emulsion process, which has now gained complete supremacy, was Bennett, in the year 1878. Bennett showed that a silver bromide gelatin emulsion gains that high degree of sensitiveness for which we praise such emulsions to-day only after prolonged warming. The preparation of the dry plates that are used to-day is based on the employment of gelatin and on the observation made by Bennett; the process is as follows.

Bromide of ammonium (in place of the bromide of potassium formerly used) is dissolved in water, and gelatin and then nitrate of silver are added, the temperature being at first kept at 75° C. [167° F.] but afterwards raised to boiling; bromide of silver is thus formed. Everything that will dissolve in water is washed out of the silver bromide gelatin emulsion thus produced; the emulsion goes solid on cooling, but after washing it is liquefied by heating, and poured on to glass plates which are dried as quickly as possible in drying racks, and are then ready to be sent into the market. The whole operation must of course be conducted in a dark room. The plates prepared in this way are about ten times more sensitive than the old-fashioned wet collodion plates.

The great development of amateur photography began with the manufacture of these plates. The preparation of sensitised plates, which up to that time had been the most difficult operation in photography, was taken away from the photographer and relegated to the manufacturer.

Excellent pictures are readily obtained by the use of dry plates provided the camera is furnished with good, and therefore expensive, lenses; and the exposure need not exceed a second, so great is the sensitiveness of these plates. The decomposition of the bromide of silver which is started at those parts of the plate whereon the light has fallen is carried to the desired extent by the developer. As soon as it is seen, by examining the plate in the red light (see forward) of the dark room, that the development has proceeded far enough, the bromide of silver which has been unacted on is removed by immersing the plate in a solution of hyposulphite of soda, and the negative is finished.

The negative is then transferred to sensitised paper, and we obtain the representation of the original object that is known as a photograph.

After the discovery that salts of silver are sensitive to light it was natural that trials should be made of the action of light upon the salts of other metals, and upon other similar substances or mixtures of such substances; these trials resulted in finding that certain salts of platinum, for instance, are sensitive to light.

If the negative obtained by using a silver bromide gelatin plate in the camera is printed on properly prepared platinum paper, which is a commercial article, a beautiful velvety black *platinotype* is obtained, the appearance of which resembles that of an engraving on copper.

The whole art of photography evidently rests on the chemical action of light on easily decomposable salts, the most important of which are to-day the salts of silver. Now the science of physics tells us that white light consists of the different colours which become visible in the rainbow. If white light is broken up by means of a prism into its coloured constituents, and if attempts are made to photograph these in the ordinary manner, it is found that no effect is produced on the photographic plate by the red rays, but that the greatest effect is produced by the rays at the other end of the spectrum, that is, by the violet rays. It is for this reason that the development of the plate taken out of the camera is conducted in red light.

In the same way it is found that yellow and green light, as well as red light, act very slightly on the plates. This fact, which is very troublesome in attempts to reproduce oil paintings photographically, makes itself apparent in portrait photography so far as the clothing of the sitters is concerned. For this reason it is necessary to correct the photographic pictures of coloured objects, especially of portraits; the correcting process is called *retouching*.

Vogel found that this inconvenience could be avoided by adding very small quantities of certain dyes to the silver bromide gelatin plates themselves. The plates are thus made sensitive to colours which do not affect plates that have not been subjected to this treatment, as the silver bromide on the specially prepared plates is acted on by light of the same colour as that of the dyes which have been added. It is only since that discovery that it has become possible to produce those beautiful photographic presentments, especially of oil paintings, that we are accustomed to see to-day. The older photographs, or those produced with the ordinary dry plates, show large portions of the originals only in a vague and indefinite manner. We may therefore look on the main part of the problem of reproducing coloured objects photographically in a proper manner as solved by the use of the *orthochromatic plates*.

But another thing remains to be done, and this is quite different from the problem we have been considering, although the two are often confused by the public, and that is to produce photographs in colours. Notwithstanding all the labour spent on this problem it has not yet been successfully solved—at any rate, certainly not as regards photographic portaiture, for coloured photographs of persons are still only produced by colouring the finished photographs by hand. On the other hand, the direct translation of the solar spectrum into a coloured photograph has been successfully accomplished. In order to obtain a photograph of the solar spectrum in its natural colours by the use of a silver bromide gelatin emulsion plate mercury is placed in the camera behind the plate, which is set with its sensitised side against the mercury. The rays of light coming from the spectrum which is to be photographed produce what are called *interference phenomena* in the glass of the plate in consequence of their being reflected from the surface of the mercury, and these interference phenomena cause the spectrum to appear on the plate, after development in the usual way, in its natural colours. The theoretical reasons of this remarkable effect have been explained in the clearest possible way. But the practical carrying out of the method is beset with such great difficulties that the production of these genuine colour photographs is successful only in a very few out of many attempts.

In addition to this coloured objects can now be most successfully reproduced in colours by a process known as *pigment printing*; but this process, as its name signifies, is not a purely photographic method.

The following is the foundation of the process. It has already been stated that, besides the sensitive salts that have been enumerated, there are many mixtures which are sensitive to light. For instance, if a solution of *bichromate of potash* is mixed with a solution of gelatin, and the sun is then allowed to shine upon any object which has been washed over with this liquid, it is found that the gelatin, which was before soluble, very quickly becomes insoluble, in water. The cause of this is that the light acts upon the bichromate of potash in such a way as to change some of it into an oxide of chromium which acts on the gelatin like a tanning agent and produces insoluble substances. We have already learnt something of the attempts that have been made to prepare chrome leather directly (see p. 147). If then a photographic negative, obtained in the ordinary way, is laid in the dark on paper covered with chrome-gelatin, the parts which the light reaches will become insoluble; and if the unattacked portions of the chrome-gelatin are now removed by washing with water in the dark room a picture is obtained which is not black, like those formed when silver or platinum paper are used, but is nearly invisible, because it is merely of the colour of the gelatin. But there is no reason why the gelatin should not be coloured with a suitable pigment before the process is carried out. Yellow gelatin will yield a yellow picture, red gelatin a red picture, and blue gelatin a blue picture; and if the three transparent delineations that are thus obtained are fastened over one another—and they must fit exactly each on the other as they are all obtained from the same negative on an orthochromatic plate—the most remarkable results are produced.

The theory of mixed colours, as developed by physicists, predicts that very brilliant results should be obtained by this method as regards the true rendering of the colours of the original objects, and the performances, especially of some of the Berlin establishments, have nearly realised these predictions. Although the process may appear from the description we have given of it to be very simple, yet the difficulties which have to be overcome in practising it successfully are very great.

There are many other reproduction methods, some of them actually in use, others in the stage of being tried; but we cannot go into these methods now. They all demand the formation of a negative by means of the camera, that is, they all begin with a representation of an object by photographic methods, and inasmuch as they do this they are all legitimate children of photography.

We cannot bring to a close our consideration of the photographic reproduction of objects without drawing especial attention to the latest advance in this department—that, namely, connected with the *Röntgen rays*, although that advance belongs rather to physics than to chemistry. Even in the first lecture we had to make an excursion into the domain of physics in order to gain clear notions about the atmosphere.

We all know that electric sparks, whether as lightning or artificially produced, pass from one place to another not by a straight but by a zigzag course. It is the resistance that the air opposes to the passage of the sparks which produces this effect. But if the sparks are allowed to pass inside a glass tube from which the air has been so completely pumped out that the internal pressure does not amount to more than about one thousandth of an atmosphere—wires having been fused through the glass at the two ends of the tube to serve as the poles of an electrical arrangement—then the tube is illuminated throughout the whole of its length when the sparks pass, inasmuch as the resistance of the air does not come into play. Wonderfully beautiful colour effects are obtained by using tubes of the kind described containing very minute quantities of different gases, such as hydrogen and oxygen, which radiate light of different colours. These tubes are called *Geissler tubes*, from the name of the celebrated glass-blower Geissler, who was the first to make them in perfect condition. If the attenuation of the air in such tubes is carried very far, as is done in the Geissler tubes, other phenomena are noticed; the sparks no longer pass through the whole tube, but bundles of rays proceed from that one of the poles which is called the *kathode*, while colour phenomena are scarcely noticeable at the other pole, which is known as the *anode*. If a bent tube is substituted for a straight one the *kathode rays* do not pass round the bend to the anode, but they proceed in straight lines, and produce a bright spot where they impinge on the walls of the tube, and this spot changes its position when a magnet is brought near the tube (see fig. 16). Hence these kathode rays, unlike ordinary light rays, are affected by the magnet.

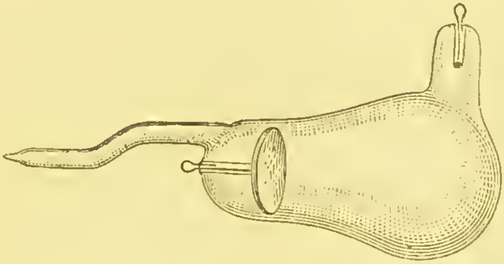

Fig. 16.

Röntgen made an investigation of the kathode rays outside of the tube wherein they were produced, carrying out his research in a darkened room. Having completely encased the bent tube in black pasteboard, he placed a paper over which was spread a solution of *platinocyanide of barium* in a position such that if the kathode rays were produced they would strike upon this paper, and he noticed that the paper began to *fluoresce*, and therefore to become visible in the darkened room. Here then he had to deal with a new and most interesting kind of rays.

By fluorescence is signified the property which many substances possess, among these being platinocyanide of barium, of converting the ultra violet rays (which we have already mentioned) into visible rays of light; the greenish sheen that is noticed in most kinds of petroleum, for instance, is due to fluorescence. The Röntgen rays resemble the ultra violet rays in that they occasion fluorescence. The fluorescence of the paper we have spoken of must have been the effect of some cause having its origin in the tube, which was completely covered, wherein the kathode rays were produced. It must be due to some kind of rays which are not perceived by our eyes, but which pass through the black pasteboard. It was also found that a book or a wooden board placed in the produced direction of the kathode rays did not stop the fluorescence of the barium platinocyanide paper when that was held on the other side of the obstruction; hence the rays are capable of passing directly through such things as a book or a piece of wood.

Röntgen then placed a sensitised photographic dry plate in the place where the paper had been, and he found that this plate was acted on by the rays that are invisible to the eye ; moreover, when he brought various substances more solid than paper or wood between the plate and the tube wherein the rays were produced, shadow pictures of these substances were obtained on the plate when that had been developed in the usual

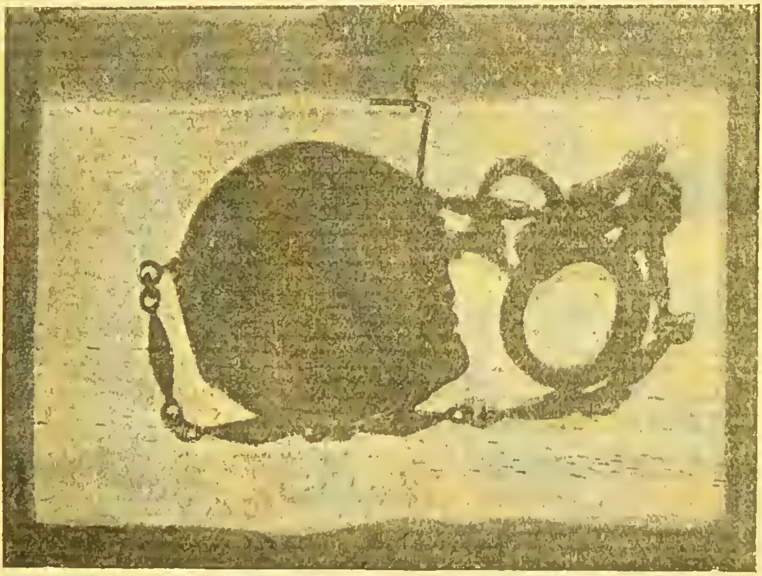

Fig. 17.

way. The figure (fig. 17) is a *radiograph* of a box containing a watch and chain.

Inasmuch as the rays pass through flesh but not through bones a shadow picture of the bony skeleton of the hand is obtained by illuminating the hand with these rays—if the expression *illuminating* may be used of rays which are invisible.

While, as we have fully described, a photograph is obtained with ordinary light after a very brief exposure, twenty minutes or more are required when working with these rays. But photographs can be taken with the Röntgen rays in ordinary daylight, for it is only necessary to place the sensitised plate in a black box, and to lay the object—the hand, for instance—on the top of this box while the rays are allowed to fall on to the object; the rays pass through the wood, which however protects the plate from daylight, on to the plate inside. These rays are not refracted by lenses; hence pictures obtained by their use are true and accurate shadow pictures of the same size as the original objects, in distinction to photographs proper, which permit of the representation of a large landscape on a space not more than one or two inches square because ordinary light is refracted in passing through lenses.

The Röntgen rays act on sensitive silver salts; but, to put the matter shortly, they are not ultra violet nor ultra red rays, because they are not refracted by lenses or prisms; they are not light, because we cannot see them; they are not kathode rays, because we see these illuminating the tube through which they pass; and as the Röntgen rays are not deflected by a magnet they are not of the nature of an electric current. They are something altogether new; and what is to be the value of this new thing, whether for science or for ordinary life, we must learn at a later time.

LECTURE XI.

Noble and base metals.—Ores.—Gold.—Platinum.—*Aqua regia.* —Separating acid.—Silver.—Relations of value between gold and silver.—Bimetallism.—Gold currency.—Reduction of metallic oxides.—Roasting sulphur compounds.—Pig iron.—Steel.—Wrought iron.—Blast furnaces.—Slags.—Coke.—Puddling.—Rolled iron.—Railways.—Cementation steel.—Cast steel.—Bessemer steel.—*Spiegeleisen.*—Manganese.—Dephosphorising iron.—Soft steel.—Gas furnaces.—Regenerative furnaces.—Open flame furnaces.—Zinc.—Electrodeposition of metals.—Potassium.—Sodium.—Aluminium.

We are accustomed to speak of two great classes of metals, the noble and the base metals. The chief difference between these classes is that the noble metals are very slightly acted on by other elements, especially by oxygen and sulphur, which are most frequently taken into consideration because of their abundant distribution on the earth's surface, whereas the base metals soon succumb to the attack of other elements, or, to express it otherwise, very readily enter into chemical combination with other elements. The noble metals, as we should expect, generally occur uncombined in the earth, and they are therefore relatively easily obtained from their deposits ; whereas the other metals have been converted in the course of endless ages into oxides by the action of oxygen, or into sulphides by the action of sulphur, or they occur in the form of yet more complicated combinations.*

That the base metals may become serviceable to mankind they must be separated by some means or other from the substances that mask them. The naturally occurring compounds of such elements are spoken of as the *ores* of the metals, when these are found in any spot in quantities sufficient to make the technical extraction of the metals therefrom profitable.

It is only in poetry that the word *ore* is used as synonymous with metal; in practical affairs it is always taken to mean, not the metal itself, but any compound of a metal which is found in nature.

It would be of little use for us to speak of all the metals in this place. In addition to certain points connected with the noble metals we shall deal in detail only with the preparation of iron, which is the most important metal in ordinary life. And in doing this we shall be able to gain some insight into the extraction of metals generally.

Gold and *platinum*, which are noble metals in the chemical sense, occur almost solely uncombined in the earth. Gold and platinum also are found in the sands of rivers, or in other deposits of sand, and they are obtained by washing these sands. When gold is found imbedded in hard rocks these are stamped and ground, and the metal is extracted, either directly, or by the help of mercury or some other chemicals that dissolve gold.

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* Miners call the sulphur compounds of metals sometimes *pyrites*, sometimes *glances*, and sometimes *blendes*. The first two have a metallic habit—lead glance, for instance—the last has not.

Gold is insoluble in every acid taken alone, and only a mixture of hydrochloric and nitric acids dissolves it; this mixture of acids was called *aqua regia* by the alchemists because they looked on gold as the royal metal. *Aqua regia* effects the solution of gold because the two acids react to produce chlorine, and chlorine attacks gold, so that the metal is found in the solution as chloride of gold. Two other solvents, namely, bromine and *cyanide of potassium*, have recently been introduced into gold mining; these are used, in addition to mercury, for extracting gold from broken quartz.

Nitric acid taken by itself dissolves silver, and for this reason this acid has been called for many ages *separating acid* (or separating water) because it is used to effect a separation of gold from silver.

The extraction of silver, except in those places where it occurs native, is by no means so simple that it can be clearly set forth here; we shall not therefore go into the methods, which are moreover all special methods for this metal, notwithstanding that the chemical improvements made in these processes have very largely contributed to the sudden fall in the price of this metal. It will be of more interest for us at present to pay some attention to the burning question of the values of the two metals gold and silver.

The oldest tidings that we have on this matter come to us from about seven hundred and ten years before Christ. A plate of gold and a plate of silver have been found in the foundations of the palace of King Sargina, who flourished about that time in the Assyrian city of Khorsabad, and these plates bear inscriptions which show that 1 lb. of gold was worth 13⅓ lbs. of silver in those days. It is very remarkable that this relation of values is found to be approximately maintained at all later times—for instance, in ancient Rome and also during the Middle Ages. The exact relation between the values of the two metals is known from 1687 onwards, because the merchants of the London and Hamburg exchanges have continued to record this relation since that year.

We find that the relation between the two metals fluctuated only very slightly until the year 1874; putting the figures into weights, 1 lb. of gold was able to purchase, on the whole, as much as 15½ lbs. of silver. But matters changed in 1874. The enormous output of silver from America, which seems as if it would be exceeded, if that be possible, by the supply coming from Australia, threw such quantities of the white metal on the market that the supply far exceeded the demand.

It does not much matter whether in such a state of affairs one has to deal with a white metal or a red metal—the price of copper, for instance, has been affected like that of silver by over production—or with grain, whatever is thrust on to the market must be allowed to go at a lower price; and so we find that the enormous increase in the production of silver, without a corresponding increase in the demand, has caused the price of this metal to fall gradually. It was soon possible to get 33⅓ lbs. of silver for 1 lb. of gold.

The relations between gold and silver are affected in the way we have described when these metals are regarded as commodities, for these relations are influenced by the same causes as those which at any time and place influence the relative values of commodities in general.

But the relations between gold and silver become much more complicated when one considers the money that is coined from the two metals.

As long as the ratio between gold and silver remained constant—and so far as those who are now living are concerned this was until about the year 1874—it did not matter in the least whether a man possessed 1 lb. weight of gold money or 15½ lbs. weight of silver money—calculated on the quantity of pure gold or silver in either—for he could exchange the gold money for an equivalent quantity of silver money, or *vice versa*, at any time he pleased.

That was the era of legitimate bimetallism. As both metals served equally well as money on account of their relatively high intrinsic values, the different states coined the two metals in the ratio by weight of 1 to 15·5. But when the time came that 16 or 17 lbs., or even more, of silver could be obtained for a single pound of gold it was of course necessary that the states should soon close their mints against the coinage of silver brought to them by private individuals. For the states were legally bound to coin the same amount of money from 15½ lbs. of silver as from 1 lb. of gold; but it had now become possible to buy 15½ lbs. of uncoined silver for, let us say, nine-tenths of a pound of gold, and indeed for a weight of gold which constantly kept getting less; if therefore they had gone on as before all the gold coins would gradually have been driven out of the countries in question. For the dealers would have sent these gold coins to other countries where they could buy for 1 lb. weight of them—always calculated on the pure metal in the coins—not 15½, but perhaps 20, or even more than 20 lbs. of silver, which silver they would have brought back to the states in question for coinage. But these states would have been obliged to make out of 15½ lbs. of silver a quantity of coins the nominal value of which should correspond with that of 1 lb. weight of gold coins, and every one in the countries in question would have been obliged to accept the silver and gold coins as of exactly equal value. In this way the dealers, at the time when the ratio was 1 to 20, would have gained 4½ lbs. weight of silver on every pound weight of gold they bought and then sold for silver which they proceeded to have coined. In quite recent times as much as 33 lbs. weight of silver could be obtained for 1 lb. of gold. Hence if the various states had continued to coin the silver brought to their mints by private people, a man who exported 1 lb. weight of gold money and sold it for silver which he then brought back and had coined would have gained, at present, as much as 17½ lbs. weight of silver. Under these conditions it is clear that not a single gold coin would be left in the countries which pursued such a policy.

By calculating the ratio of weights that have been mentioned into gold we get the following result. Until the year 1874 an ounce of silver cost about 60 pence in London, which has always ruled the market for the noble metals, and the price hardly varied from year to year; but at present an ounce of silver can be bought for about 27 pence.

As the inhabitants of the German Empire have a gold standard they are independent of fluctuations in the price of silver; for the law declares definitely that 200 marks are to be coined from one kilogram of silver, and that this coining is to be at the rate of 10 marks per head of the population. Therefore 20 marks in one-mark silver pieces are not of nearly the same intrinsic value as one 20-mark gold piece; for if these twenty coins were melted into a lump of silver, that lump, which would of course contain 100 grams of uncoined silver, would only be saleable by weight, and would not fetch more than about 9 marks, as the present selling price of silver is about 90 marks per kilogram.

The action of the law has caused the twenty one-mark pieces to be worth much more than the silver in them was worth before coining; and at the same time the law lays it down that no one is obliged to accept more than 20 marks in silver in payment of a debt.*

It is certainly very remarkable that there should be throughout Europe a party, known as the bimetallists, who hope for the cure of all agricultural difficulties, or we may say for the better payment of all labour and every possession, by restoring, wherever possible, the ratio between the values of gold and silver to 1 to 15½, and that this party should be very eager at the present time. The less violent partisans of this theory would be content, it is true, with establishing the ratio at 1 to 22 for the present—for the bimetallists are not unanimously agreed as to what they really want—while, as a matter of fact, the ratio keeps fluctuating around something like 1 to 30.

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* Silver coins are legal tender up to 40 shillings in this country.—Tr.

But it is just this fluctuation which makes any form of bimetallism impossible to-day. For if the various states should resolve, by an international agreement, once more to coin gold and silver money in a fixed ratio, say 22 lbs. weight of silver money for every pound of gold money, the effect of this would be to make silver more valuable, and so to cause the proprietors of silver mines throughout the world to increase the production of silver—the increase of which destroyed the old bimetallism, for that was in no way regarded by these silver owners while it existed—and this increased production would go on until an end should happily be made of the new international bimetallism.

Nothing could be done without an international agreement; for if a single state were to coin all the silver that might be brought to its mints into money at a ratio more favourable than the ratio of 1 of gold to 30 of silver, that state would be depleted, as we have already said, of all its gold coins in a few weeks.

Those countries, then, are best off which have a gold currency. The inhabitants of such countries have a stable standard of value, which is not subject to fluctuation, for all those things that can be compared in terms of gold, and for this reason we see that all civilised states that have not already a gold standard are endeavouring to acquire that standard. A few years ago the bimetallists disturbed people's minds by asserting that there was not nearly enough gold to make it possible for every country to have a gold standard, and that sufficient gold money could not be coined to supply the wants of commerce. But this trouble has disappeared, so far as the present generation is concerned at any rate, since the abundant finds of gold in South Africa.

There is one thing which the bimetallists would certainly achieve, as long as they do not get rid of the fluctuations in the price of silver, were they to induce the civilised states to inaugurate an international bimetallism in that Utopia which they depict to any one who will hearken to them as the approaching economical rejuvenescence of the nations—for none of them has brought forward a decisive argument in favour of their assertions because no such argument exists, for if there were such an argument it would certainly be easy to induce the most influential nations to adopt bimetallism again—and this one thing which they would undoubtedly do would be to enable the proprietors of American and Australian silver mines, one of whom is already the richest man in the world, to make yet much greater profits from their mines, in which profits Europeans have as yet no great interests. Compared with these, the profits of the European silver producers could not be large because of the smallness of the production.

All the other advantages which the bimetallists assert are to accrue to Europe by the adoption of their proposals rest on ways of looking at the matter about which they are exceedingly enthusiastic, but in support of which they cannot adduce any solid proofs, while at the same time they construct plenty of theoretical arguments which do not fail to produce an effect on those who do not thoroughly understand the matter.

One cannot then be astonished that the number of those who support bimetallism has much increased since it has addressed itself to the general public. Most of the frequenters of the meetings of bimetallists do not grasp as a whole the matters that are put before them because of the many difficulties of the subject; but still they are quite sure that restored bimetallism—that mystical word—will bring with it at least a part of the good fortune to which each one thinks he has an undoubted claim, and for that reason matters will be different with them then. Did not some of the troops who were at St. Petersburg in 1826 at the enthronement of the Tsar shout *Long live the Constitution* instead of *Long live Constantine*, because they had been told that the name of the new monarch was *Constitution*?

The base metals, to which we now proceed, are extracted from their ores which are for the most part either oxides or compounds of the metals with sulphur. The process of extracting the metals from their oxides consists in heating the oxides mixed with coal or charcoal in suitable furnaces, whereby the oxide is said to be *reduced to metal.*

$$\text{Oxide of iron} + \text{carbon} = \text{iron} + \text{carbon monoxide.}$$

To convert the sulphur compounds into oxides, and so to obtain compounds from which the metals can be extracted on the large scale, it is necessary to roast the sulphides in the air; in this process the sulphur is burnt to sulphurous acid, and the metal to oxide which is then reduced by heating with carbon. For example:

Sulphide of zinc + oxygen (from the air) = sulphurous acid + oxide of zinc.

Were the sulphurous acid to escape into the air it would destroy all the plant life in the neighbourhood (see p. 193 *note*); it is therefore generally nowadays collected, by the help of improved arrangements in the furnaces, and converted into sulphuric acid. The equation just given represents the carbon as being burnt only to carbon monoxide when a metallic oxide is reduced to metal by heating with carbon, whereas in other cases we saw that it was burnt to carbonic acid. The reason for this is that the temperature required for the reduction of the metallic oxides is so high that at that temperature the carbon is able to bind to itself only a single atom of oxygen; the carbon monoxide that is formed in this way can at another time combine with a second atom of oxygen and thus be burnt to carbonic acid. We have gone into this matter with some fulness because we shall have to make use hereafter of this more accurate statement of what occurs in these processes.

We shall now make a more special study of the extraction of iron. Three sorts of iron have been distinguished for very many years.

Pig or *cast iron*, containing from about 4 to 5 per cent. of carbon;

Steel, which contains much less carbon than pig iron, but more than the third variety;

Wrought iron, containing about half a per cent. of carbon.

Pig iron is fusible, and can be cast; steel can be worked in the forge, and the articles made in this way can then be tempered ; wrought iron can also be forged, but not tempered afterwards.

Many other kinds of iron are distinguished in the iron manufacture of to-day, but we shall discover that the preceding classification is amply sufficient for our purposes.

All commercial iron then contains carbon. While it is well known that endeavours are made to obtain all other metals as free from impurities as possible, because their peculiar properties are then most distinctly apparent, the case is different with iron. The contamination of iron with carbon, if such an expression may be used in this connection, is required in order to give to the iron those diverse properties which make it the most serviceable of all the metals.

Iron takes up as much as 4 or 5 per cent. of carbon only at a very high temperature ; hence pig or cast iron was quite unknown to the ancients. Wrought iron, however, has been known for ages. A piece of this iron was found in one of the pyramids, built it is thought about four thousand nine hundred years ago. The production of this iron, however, depended on the degree of civilisation of a people, for it is told by Cæsar that when he came to Britain about 50 A.D. gold and iron were nearly equally valuable there, as the inhabitants possessed only those small quantities of the two metals which were brought to the country by traders. Methods of extracting iron were unknown at that time in England, which is the country where the most important discoveries in that direction were made at later times, and which is also the country whose output of iron has been for centuries greater than that of any other, and has only been exceeded within the last few years by that of the United States of America, a country with an area enormously greater than the area of England. The extraction of iron cannot be made clear except we first realise the method and manner of the production of the high temperatures that are required in the processes; we must therefore approach the subject of the manufacture of iron from this side.

If wood or coal, or other combustible material, burns on the ground only a flickering fire of little use as a source of heat is obtained, for the supply of air, which is needed for burning the carbon, is very limited. But matters are soon altered if the heating material is burnt on a support that is perforated so that the air can enter from beneath. We do this when we burn a fire in a grate; and if we also insure the speedy removal of the carbonic acid and the other products of combustion by fixing an exit pipe at a proper distance above the fire, then the regular stream of air which flows into the fire brings about a uniformly rapid combustion of the materials in the grate. A pipe of this kind, which takes the form of a chimney in a dwelling house, acts as a means of producing a draught, for the carbonic acid formed in the burning and the nitrogen that comes in with the air, being much heated by the fire, become lighter, bulk for bulk, than the surrounding air, and therefore tend to ascend, and hence to cause a current inwards of fresh air to supply their place.

Many metallic oxides may be reduced in a fire of the kind described with the help of carbon, but oxide of iron cannot be reduced. This oxide is reduced only when the fire is saved the trouble of sucking in the air by the air supply being blown into the fire, whereby a very rapid combustion is of course produced. Every smithy fire is an arrangement of this kind wherein the fire is blown up by the smith's bellows.

The ancients reduced oxide of iron in a smithy fire; they sometimes obtained wrought iron and sometimes steel, for, according to the manner of working, sometimes less and sometimes more carbon entered into the iron, and it is upon the quantity of this constituent that the production of one or the other of these varieties of iron depends. The results were better or worse according to the purity of the iron ore used and the skill of the workmen who handed down the art from one generation to another; and hence came the great reputation of the blades of Damascus and Toledo, for instance; for the production of steel, which is a very difficult art when only a smith's forge is available, had become a speciality of these districts and had been brought to great perfection.

Only those iron ores which are comparatively easily reduced can be worked in a smith's forge. But the production of iron spread gradually to different countries, and as easily reduced ores were not to be had everywhere it became necessary to find means for increasing the heat of the furnace. This was done by building stones around the smithy fire and so converting it into a blast furnace. The heat of the fire was not then lost in warming the surrounding air, but the stones became red hot and so concentrated the heat more in one place, and the temperature was raised so much that the reduced iron took up four, or more than four, per cent. of carbon, and the pig iron thus produced ran from the furnace in a liquid state. This discovery seems to have been made in the southern part of Alsace near where the town of Mulhouse now stands; at any rate the oldest specimens of pig iron that are known came from that neighbourhood about the year 1490. The invention of pig iron was made about the time that saw the discovery of America.

The manufacture of pig iron spread somewhat slowly, and it was not till 1547 that it began to be practised in England. The first iron smelting in Prussia, the territorial extent of which was very different at that time from what it is now, took place in 1667.

The blast furnaces that are in use to-day are enormously larger than those of these early days (see fig. 18). With regard to the production of iron in these furnaces, the following points should be particularly noticed. The iron oxide is reduced to iron by the carbon (coal) in the furnace, and the iron sinks gradually downwards until it comes to a part of the furnace which is so hot that it takes up a quantity of carbon sufficient to cause it to melt; but after that the molten iron has to pass the zone whereat the air is blown into the furnace, and at this place it would be again burnt to oxide of iron were not an especial precaution taken to prevent this. The formation of slag is the precautionary measure that is adopted.

Slag is a kind of glass, and therefore it consists of double silicates (see p. 214). Besides oxide of iron and coal, limestone and clay (the latter is a silicate of alumina), and when necessary sand also, are thrown into the blast furnace. These things vary in different neighbourhoods and also in accordance with the constituents of the ores that are to be smelted, the most easily accessible and the cheapest substances that are suitable for the purpose being chosen. Those that have been mentioned are the most commonly used; at the temperature of the furnace they react to form a double silicate of lime and alumina, which is a kind of glass.

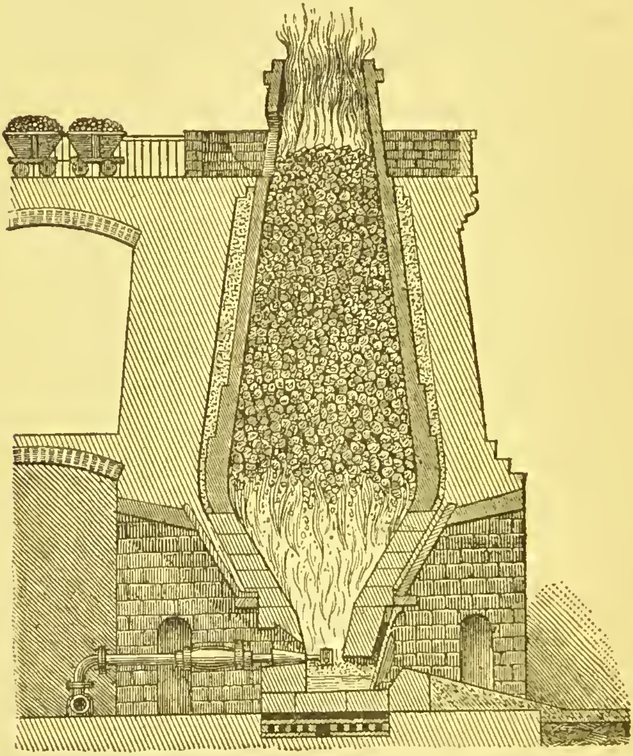

Fig. 18.

The mixture of the substances that are to produce the slag is always selected so that they run together to a glass only after the iron has taken up enough carbon to convert it into pig iron; this glass then covers the individual molten particles of iron and protects these from the effects of the air blast. And in this way the iron passes the zone where the blast is sent in without being reburnt to oxide. Lower down in the furnace the heavy liquid iron separates from the lighter melted glass, and both flow out of the furnace as liquids.* When the iron solidifies it is called pig iron, and the solidified glass is called slag. It was only after the discovery of pig iron that iron making became a great industry in the

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* The representation of the blast furnace in fig. 18 is partly diagrammatic, because such a representation elucidates the preparation of pig iron better than an exact drawing of one of the monstrous modern furnaces would do. A modern furnace requires six or seven pipes for blowing in air [called *tuyeres*], whereas only one is represented in the figure. Moreover the furnace is shown open at the top whereat the flames are escaping; but this is not the case in actual furnaces nowadays At the point where the air blast enters the furnace—and the air is strongly heated before it is blown in—the carbon of the coal is burnt to carbonic acid; but this extremely hot gas reacts with the higher layers of hot coal to form carbon monoxide. Thus

$$CO_2 + C = 2\,CO.$$

One molecule of carbonic acid + one molecule of carbon = two molecules of carbon monoxide.

Hence carbon monoxide, which is an inflammable gas, escapes from the furnace. In older times this gas was allowed to burn at the mouth of the furnace, and so to be lost (as is shown in the figure); nowadays the furnace is closed by a hood, and the carbon monoxide is led from under this hood to places where it is burnt, and the heat is used for evaporating, or for heating the air to be sent into the furnace, or for other purposes of a similar kind.

modern meaning of that term—that is, one of those industries that never dream of a night's rest. Up till that time the smith could get ready each day two or perhaps three blocks of iron, each weighing about 80 lbs., and these he might or might not work up the following day. But the preparation of pig iron is carried on in quite a different way. When a blast furnace is started it must be kept going day and night, else it would never get hot enough to melt any iron at all; but in return for this the furnace produces large quantities of pig iron, which has thus become a cheap commodity.

Pig or cast iron then contains from 4 to 5 per cent. of carbon, and if it were possible to burn away a part of this carbon, either steel or wrought iron (see p. 265) would be produced. And such a burning off of carbon is actually accomplished. When pig iron is heated in a forge fire with free access of air a part of the carbon in the iron is burnt away, the mass becomes pasty and does not run to a liquid, and either steel or wrought iron is formed according to the skill of the workman. It is much easier to make wrought iron than steel in this way, because it is very difficult to hit the point whereat just enough carbon is left in the iron to give it the properties of steel. But in making wrought iron it is only necessary to burn away as much of the carbon as possible, for enough always remains to give the whole of what is left the qualities of wrought iron. Now it was found to be so much easier to make wrought iron from pig iron than to manufacture it directly from the ores by the older process, which was the only method available before the discovery of pig iron, that the ancient method was soon abandoned, and as a consequence the manufacture of pig iron in the blast furnace has become the foundation of the whole iron industry.

This condition of affairs had been attained as early as 1620. The manufacture of pig iron had become a large concern in England by that time, as the conditions were more favourable in that country than elsewhere. The intelligence of the inhabitants eagerly turned to the best account the large quantities of iron ores that were raised in that country, and the many rivers made it possible to transport the prepared iron without difficulty to other lands. The roads at that time, being badly constructed and easily disturbed by rains, were not adapted for the transport of great quantities of iron; hence the manufacture of iron could not be carried on profitably at any great distances from rivers or from the sea.

Wood charcoal was employed as fuel in the blast furnaces; but the great demand for wood led to the visible disappearance of the forests—independently of the destruction of forests, which was but little heeded in those days—and to the imperative necessity of finding some substitute for wood. Coal at once suggested itself. But a blast furnace cannot be worked with coal as the fuel; for before it burns, coal becomes pasty and tarry matter distils from it, and if coal were used in the blast furnace the single pieces would get glued together so that the air blast could not penetrate the mass, and the working of the furnace would be stopped.*

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* Nevertheless, bituminous coal is used in blast furnaces in Scotland and North Staffordshire, and in parts of the United States.—TR.

The suggestion was made to change coal into coke—that is, to heat the coal in a closed vessel where it cannot burn for lack of air. All the volatile and fusible matters in the coal are driven out by this treatment, and a hard mass remains, which can be used as fuel in the blast furnace because it will burn without caking together. In making coke for use in the blast furnace no attention is paid to the volatile matter of the coal; it is only the residue—the coke—that is important (cf. pp. 30-32).

Coke began to be used in blast furnaces about the year 1700; and as it then became possible to obtain any desired quantity of fuel the production of cast iron went on increasing very considerably until about the beginning of this century, when that enormous advance began the end of which we cannot yet see.

Coke is so hard that a blast furnace may be built about 30 metres [92 feet] high without the contents getting crushed and crumbled. In the older days it would not have been possible to get the enormous quantities of raw material which such a furnace requires into the furnace; and it was only after the invention of steam engines and railways that it became possible to feed furnaces of such a size.

A blast furnace using charcoal as fuel, such as may be found at work to-day in Styria, could turn out daily, towards the end of last century, from 3,000 to 4,000 kilograms [nearly three to four tons] of cast iron; but a blast furnace at Pittsburg in America, using coke, produces daily about 250,000 kilograms [about 245 tons] of the same substance.

While the mechanical parts of the operation of iron smelting were being brought to perfection chemistry was busily engaged in trying to elucidate the processes that occur in the blast furnace, for these processes are certainly not so simple as we have represented them in the sketch that has been given. And since it has become perfectly clear that the properties of different kinds of iron are conditioned by the percentage quantity of carbon which each contains—a statement that is far from being self-evident—advance has ceased to be slow; and indeed such rapid progress has been made on the basis of this knowledge that the present generation may be said to be passing from the age of iron to the age of steel.

The remark has already been made that scarcity of charcoal led in England to the erection of blast furnaces which should use coke as their fuel. All the pig iron obtained by the use of these furnaces, except what is employed for making articles of cast iron, was, and is, manufactured into steel or into wrought iron. The preparation of wrought iron was carried on in small furnaces with strong air draughts, wherein the 4 or 5 per cent. of carbon was gradually burnt away until only about ½ per cent. remained; the product was wrought iron. It was necessary to use charcoal for this purpose because the ashes of coal or coke contain substances which react chemically with the iron while it is being worked up with the fuel in such a way that the wrought iron produced is quite useless.

While it was possible many years ago to obtain cast iron, produced in large works, in quantity and at a low price, wrought iron long remained as expensive as it had ever been, for it was still made on a small scale, and each lump of iron was worked on the hearth of a furnace, just as used to be done in olden days; and in addition to this, charcoal, which is an expensive fuel, was used in making it.

But a revolution was brought about by the discovery made by Cort, an Englishman, and patented by him in the year 1784. Cort hit on the plan of separating the fire from the pig iron in making wrought iron; as the ashes of the combustible material were thus prevented from coming into contact with the iron these ashes had no influence on the product. He carried on the making of wrought iron in a reverberatory furnace; and his process, which is called "puddling," has remained in use until now, although changes, to which we shall refer immediately, have been made in the arrangement of the furnace. In a reverberatory furnace it is only the flame of the burning fuel that plays on the iron (see fig. 19).

This process is capable of manufacturing large quantities of wrought iron, inasmuch as a great many pigs of iron may be placed at the same time on the bed of the furnace, which is separated from the fuel by the fire bridge, and the carbon of these pigs will be gradually burnt away until only a very little is left; and as the furnaces must be kept working uninterruptedly day and night, that the proper temperature may be maintained, the manufacture of wrought iron has become one of those industries that are conducted on a very large scale.

Previous to the improvement made by Cort it had been customary to hammer out each lump of iron, as it was made in the forge, by hand, or by the use of a somewhat larger hammer worked by a waterwheel. The surfaces of the articles of wrought iron made by this older process were never quite smooth, and the marks of the blows of the hammer could be seen upon them, even on iron bands, which to-day are made as smooth as if they had been polished.

The masses of wrought iron produced by the older methods of puddling were not at all amenable to further treatment. Cort therefore introduced the rolling of wrought iron. He shaped the pieces of iron that left the furnace into the desired forms by squeezing them while red hot between rollers (see fig. 20). If the two rollers work close on one another, and corresponding pieces are cut out of the upper and under rollers, band or square iron is obtained, and if the indentations are truly cut the bands must come out of the rolling mill with perfectly smooth surfaces. If a cutting the shape of the top of a modern railway rail is made in the upper roller, and one which has the

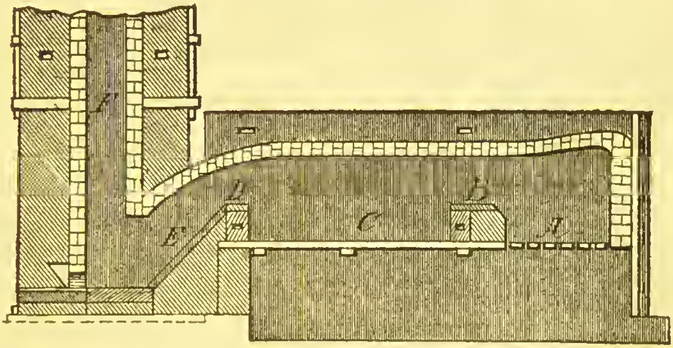

Fig. 19.

A, Grate, whereon the fuel is burnt. *B*, Fire bridge. *C*, Furnace bed, whereon the iron is heated. *D*, Flue bridge. *E*, Flue. *F*, Chimney.

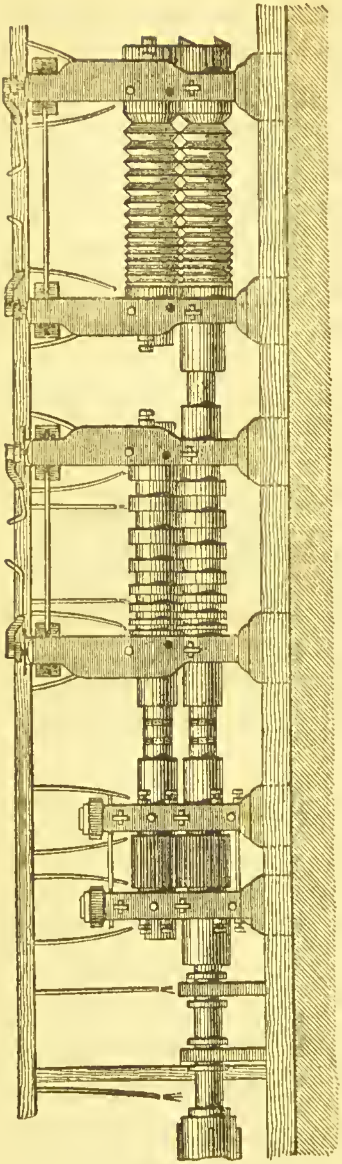

Fig. 20.

form of the lower part of such a rail is made in the under roller, then the rolling mill turns out rails. A sheet of iron is obtained by passing a piece of iron between two smooth rollers fixed at a convenient distance from one another; and so on. The water which trickles on to the rollers (see fig. 20) serves to cool them.

Like many other great inventors, Cort derived no material advantages from his ideas and labours which have done so much to advance civilisation. The many researches that were needed to bring his ideas into practicable shape swallowed up his means, and he died in poverty.

James Watt had invented the steam engine as long ago as towards the end of last century. But the work which the engine could do was very limited, because the steam that was needed to keep it going could be produced only in cast-iron boilers, and no one at that time knew how to make these of considerable size. This was not changed until the process of rolling iron made it possible to manufacture large uniform plates of wrought iron. Large boilers can evidently be made by riveting such plates together,* and such quantities of steam can be produced in these boilers as suffice to set in motion the largest machines.

Attempts began to be made in the early years of this century to employ steam engines in place of horses for traction purposes.

As has been mentioned, most of the English mines are situated near rivers, and it was long ago customary to lay down wooden tracks for the easier conveyance of heavy loads from the mines to the rivers; sleepers were placed on the ground, and then joined into a continuous track by long pieces of wood. In order to do away with the need of frequently renewing the long pieces of wood between which the horses walked the custom was to lay boards over these, so that when the boards were worn out by the passage of the wheels over them they could be replaced by others.

In the year 1767 the iron industry was affected by an extraordinary crisis, which became so severe that at last cast iron was quite unsaleable. A large iron works that had a considerable stock of pig iron cast a part of its stock into oblong plates, that the iron might not be lying altogether useless, and laid these down on the foundations of a wooden tramway in place of the boards that had been used before; this road thus became the first *railway*, as we call such a construction nowadays.

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* Steel plates are used nowadays.

The experiment turned out a great success. The horses were able to draw much heavier leads on this smooth support than on the boards that were formerly used, and the wear and tear of the iron was extremely small. When the crisis in the iron trade was over not only did this railway remain, but all the other works gradually adopted the new contrivance.

Here then, in the literal meaning of the word, was laid the foundation for steam carriages. Stephenson had about that time constructed the first locomotive that was of practical use for the conveyance of human beings.

An examination of the English patent literature of that period shows what a vast number of proposals was made, and how many investigations were undertaken, with regard to steam carriages, all of which came to nothing; and it also makes one better appreciate the esteem in which his contemporaries held the discoverer who at last hit upon the true solution of an extremely difficult problem which had been attacked by so many others.

After the invention of the process of puddling it was easy to obtain both cast and wrought iron; but circumstances still remained very unfavourable to the production of steel, which is the most valuable form of iron so far as usefulness is concerned.

It is just as difficult to make steel from pig iron by puddling as it used to be to make wrought iron by the old forge method. There is no theoretical objection to the method, for all that need be done is to stop the puddling when the iron contains just enough carbon to form steel; nevertheless this can scarcely be done in practice.

But as long ago as the beginning of last century, and therefore long before the invention of puddling, a new method of preparing steel was found out in Northern France; the steel made by that method was known as *cementation steel.* The earliest truly scientific work on this subject was carried out by Réaumur, who lived at that time, and whose name is generally known in connection with the thermometric scale which he introduced.

If sufficient carbon could be added to wrought iron to bring up the quantity of carbon from $\frac{1}{2}$ to about 2 per cent., then, in accordance with the sketch given on p. 265 of the different kinds of iron, we should expect that steel would be produced. The preparation of cementation steel depends on this principle. The wrought iron is cut into bars, and these are packed in charcoal powder in fireclay chests, set in a convenient manner in a furnace which is kept heated for a period of six to eight days. Under these conditions a gradual permeation of the iron by the carbon takes place, and the iron is changed completely into steel.

Steel made in this way cannot be quite homogeneous, for the outer parts of the bars will be richer in carbon than the inner portions. A remedy for this was sought in the vigorous working of the steel under the hammer.

In 1750 an English watchmaker called Huntsman discovered a perfectly homogeneous steel that cannot be surpassed to-day. He found, as every one else did, that very many of the watch springs he worked with snapped, because of the unequal character of the steel of which they were made, and in attempting to remedy this he discovered that small quantities of cementation steel could be melted in crucibles placed in an extremely hot furnace.

This can be easily understood by us; we know that iron containing 4 per cent. of carbon melts comparatively readily, and there seems to be no reason why iron containing less carbon should not also melt if a sufficiently high temperature can be attained.

The cast steel discovered by Huntsman is perfectly homogeneous throughout, and, as the hardness of steel is not diminished by melting, this cast steel is a material that cannot be replaced for many purposes by anything else. The method of manufacture remained a secret with certain English makers who asked fancy prices for their steel; and these prices were paid because a material equally suitable for many purposes could not be obtained anywhere else. Many efforts were of course made to find out the method whereby this English steel was secretly manufactured. The founder of the Krupp iron works was one of the most determined workers in this direction, and although he did not live to see the problem solved completely his son succeeded in producing such perfect cast steel that Krupp's works have become the largest iron manufactory in the world.

Cast steel of this kind leaves nothing to be desired, but it must always be expensive because of the great number of processes required in its preparation; for pig iron must first of all be made into wrought iron, and this must then be caused to combine with carbon, and finally the steel must be melted in crucibles in an extremely hot furnace.

The world has been supplied with cheap steel by Bessemer since the year 1856. His process converts molten pig iron into cast steel without the consumption of fuel.

For this purpose Bessemer brings the melted pig iron into a pear-shaped vessel, provided at the bottom with a row of pipes for blowing in air (see fig. 21). The vessel [which is called a "converter"] is constructed of iron plates riveted together, and to enable it to resist the high temperature attained in the process it is lined with an extremely fire-resisting material consisting almost wholly of silicic acid, to which we must pay especial attention.

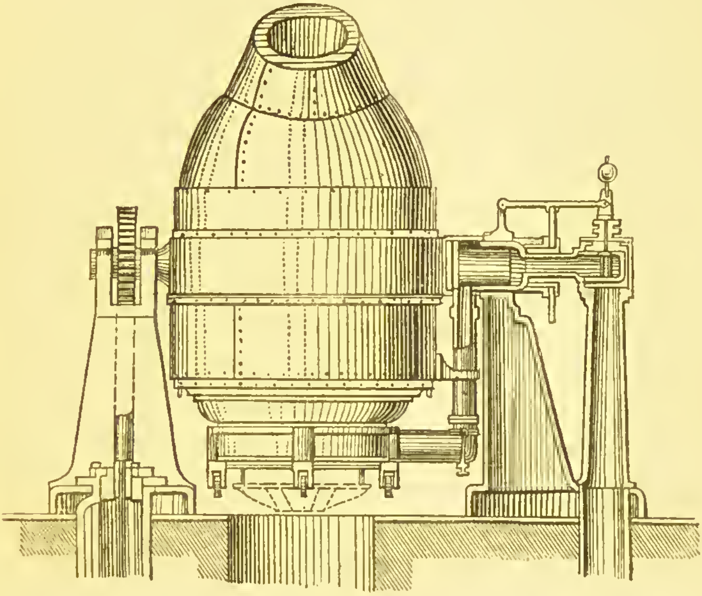

Fig. 21.

The converter is inclined horizontally [it rotates on trunnions fixed on both sides somewhat lower than the middle of the vessel] and the melted pig iron is run into it, and while it is being brought into the vertical position air is blown in through the pipes in the bottom. The red-hot carbon * in the glowing iron at once begins to burn, and this combustion produces heat enough to keep the contents of the converter melted. After about ten minutes the carbon is all burnt off, and the contents of the converter would be valueless were not sufficient pig iron added, at this moment, to supply just enough carbon to convert the whole mixture into steel.

The iron that is added for the purpose of supplying carbon is purposely selected because of its richness in *manganese*, an element that is closely allied to iron, for the presence of manganese exerts a beneficial effect on the product in a way that we cannot inquire into here. The word *spiegeleisen* † is often met with; it is the especial name for a kind of pig iron that contains manganese and shows a lustrous surface when broken.

Pure manganese is manufactured in some of the metal smelting works to-day for the purpose of being used in the Bessemer process, for this metal taken alone has not as yet found any industrial applications.

The Bessemer process enables steel to be manufactured on a very large scale, for a single converter will contain from 5,000 to 10,000 kilograms [approximately 5 to 10 tons] of pig iron, and the whole of this is converted into steel in a quarter of an hour.

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* And also the *silicon* which gets into the iron in the processes that occur in the blast furnace; for at the high temperature of that furnace a little silicic acid, which consists of silicon and oxygen, is reduced to silicon, which mixes with the iron.

† *Sparkling iron;* the German term is generally used in English books.—Tr.

Before leaving the Bessemer process we must say a little regarding the dephosphorising of iron, a process which should further cheapen the cost of steel.

Most of the iron ores that are found native contain phosphorus. The pig iron that is made from such ores also contains phosphorus, and unless the quantity of phosphorus is extremely small this iron is of a poor quality, and is only fitted for making the coarsest sorts of cast-iron ware, such as railings for graves and the like, in which no great durability is looked for; such pig iron could not possibly be worked up into wrought iron or steel. The analyses of pig iron made between 1830 and 1840 showed that phosphorus is the cause of this behaviour. It was also known at that time that no method was to be found for keeping the phosphorus contained in the ores out of the pig iron during the processes that go on in the blast furnace; nor has any method yet been discovered.

Notwithstanding the almost constant attempts to dephosphorise iron no result worthy of mention was obtained until Thomas and Gilchrist finally solved the problem in the most ingenious way.

Many investigations had proved that the original Bessemer process does not remove a trace of phosphorus from the iron used. All the phosphorus in the pig iron employed remains in the steel that is produced, and therefore in the rails, or the axles, or the surgical bandages, etc., made of that steel. As regards rails, one-tenth, or at the outside two-tenths, of a per cent. of phosphorus might be permitted; but for all other applications of steel the presence of even the tenth of that quantity is quite out of the question.

The raw material suitable for the old Bessemer process, which is dependent on the use of iron ores free from phosphorus, is found, so far as European interests are concerned, only in the red iron ores, containing no phosphorus, which occur in Cumberland and Westmoreland, in Spain, Algeria, Styria, and in the Siegen States.

An immense sensation was produced among those connected with the iron industry by the announcement, in 1879, that pig iron containing phosphorus had been converted into steel free from phosphorus in the Bessemer converters of Bolckow, Vaughan, & Co., the largest iron works of the Cleveland district.

Before the discovery of the Bessemer process the rails that were manufactured for railways were made of wrought iron because steel rails could not be procured easily; but this was completely changed by that discovery. Because of their much greater durability, the steel rails that are turned out so cheaply by the Bessemer process have completely taken the place of the iron rails that were formerly used.

A large steel rail industry sprung up in Cumberland, but this industry did not flourish in Cleveland, where the iron ores are unsuited for making this kind of steel because of the phosphorus they contain. And the manufacture of wrought iron rails which had been carried on at Cleveland, for the ores of that district contain but small quantities of phosphorus, had to be abandoned, because the use of such rails was being gradually dropped by the railway companies, who were more and more favouring the employment of steel rails.

The Cleveland manufacturers then determined that they also would manufacture steel rails, and that they would turn their great appliances to the best account by making use of Spanish ores which contained no phosphorus. So they manufactured pig iron for making Bessemer steel from these ores, and their undertaking was crowned with success.

But the Cleveland iron masters were not satisfied; they set themselves with determination to solve the problem of finding a method which would allow them to use in the Bessemer process the iron ores that were so plentiful in their district, which were indeed almost lying at their door. And the technical chemists Thomas and Gilchrist, whose names have been mentioned before, succeeded at last in the following way.

We laid stress on the fact that in order to make his converter withstand the action of heat Bessemer lined it with a very fire-resisting material which contained much silicic acid, and which in a chemical sense was therefore acid. Thomas and Gilchrist, on the other hand, lined the converter with a basic lining which contained much lime.

At the high temperature which is attained in the converter the carbon of the pig iron is burnt, as we have seen; and, as we should expect, the phosphorus is also burnt, and burnt to phosphoric acid. But whereas in the original process this phosphoric acid remained in the molten mass, in the modified process it is able to combine with the basic lining, it enters into union with the lime and forms phosphate of lime.

And so the problem of dephosphorising iron in the Bessemer converter was solved. The pig iron that contained phosphorus yields steel that is free from phosphorus, because the phosphorus is held fast, as phosphoric acid, by the basic lining.

When the phosphate of lime formed in the linings is finely ground it forms what is known as Thomas's phosphate powder, and is used by farmers for manuring meadow land (see p. 46). And thus it is that the phosphorus which was formerly so harmful becomes saleable in this form, and so bears its part in reducing the cost of steel. The fact that iron ores containing phosphorus are cheaper, because they are obtainable all over the world, than those that are free from phosphorus, also tends in the direction of cheapening steel.

It must not be supposed, as might perhaps be imagined from what has been said, that the process of these fortunate inventors fell into their hands from the skies. On the contrary, it was the fruit of year-long labours and of a decade of arduous exertion. The preparation of a sufficiently fire-resisting basic lining for the converter alone consumed the labour of many years and a large expenditure of money before it was possible to be certain that the considerations which had led to the choice of this material would prove themselves workable on the large scale.

Inasmuch as most epoch-making discoveries are the products of many years of toil, and are not as a rule isolated brilliant ideas, it often happens that disputes about priority arise after these discoveries become known. Thus we find that the idea of using a basic lining in the Bessemer converter for the purpose of removing phosphorus was suggested in the literature pertinent to these subjects in various countries in 1875 and again in 1878. But it seems to have been regarded as an impracticable undertaking; yet the question was solved in 1879 in this very way in England.

Another and quite different method for making steel may be supposed possible. Cast iron contains from 4 to 5 per cent. of carbon, and wrought iron contains about ½ per cent; if a mixture of these two in the proper proportions were melted a mean product which would have the composition of steel would be obtained.

The difficulty that prevented, for a long time, the carrying of this idea into practice was that no reverberatory furnace could be constructed to give a sufficiently high temperature to affect the solution of wrought iron, which is infusible in an open furnace, in molten cast iron so as to produce steel.

The French manufacturer Martin was the first to produce this *soft steel*; but Siemens had constructed furnaces in 1885 wherein such steel could easily be prepared.

In speaking of puddling, we mentioned that that process had remained essentially unchanged since Cort's discovery, except as regards the methods of heating the furnaces. Only those very good, and therefore expensive, sorts of coal which burn with a long flame could be used in the puddling furnaces, as it was necessary that the heat should be obtained from the flames which shot out from the grate over the fire bridge. But nowadays the heating is done by gas which is produced on the spot from what are called *generators.*

For the purpose of heating by gas, fuel, which need not be of first-rate quality, is shot from a height on to a grate. Under these conditions the quantity of air in contact with the fuel is not sufficient to burn the carbon completely to carbonic acid, and therefore carbon monoxide and other combustible gases escape from the generator.* It must be noticed that the whole of the nitrogen in the air that enters the furnace through the grate is found in the gases which escape from the generator.

The chief difference between such generator gas and ordinary coal-gas, the latter of which is obtained by heating coals in closed retorts (see p. 30), is that the coal-gas does not contain nitrogen and consists only of combustible gaseous substances.

The hot gases which come from the generator are burnt in reverberatory furnaces into which air is conducted. The gases pass through passages in the walls of the generator whereby they are heated.

The most important improvement made in heating by gas consists in the adoption of *regenerators.* When the gas had done its work the hot mixture of the products of combustion used to be allowed to escape by the chimney. But the regenerators retain the heat of the burnt gas. For this end the burnt gas, which has fulfilled its special purpose, is led through chambers which are built with cross-bars made of fireclay bricks, and it is not until it has given up its heat to these chambers, which are thereby raised to a full red heat, that it is allowed to escape by the chimney. These chambers form the regenerator. When the gas leaves the generator in which it has been produced it passes through the red-hot chambers of the regenerator and is thus made very hot, and it is then allowed to come into the reverberatory furnace, where it meets with sufficient air to burn it. The air is also passed through a red-hot regenerator before it enters the furnace, and it carries with it into the furnace the heat which it has taken up in its passage.

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* The reactions have been more thoroughly described in the note on p. 271.

As the chambers of the regenerator can be connected and disconnected by means of valves, they can be heated in turns so that red-hot chambers are always ready for heating both the gases and the air, and as soon as these chambers have given up their heat they can be heated again. The saving of fuel effected by this method, as compared with the old processes, amounts to from 40 to 50 per cent.

Notwithstanding the application of generators and regenerators to reverberatory furnaces, it was still impossible to manufacture soft steel or soft iron (for these are the names given to the steel produced by melting together wrought and pig iron) in such furnaces. The *open flame furnaces* invented by Siemens made this possible for the first time. From theoretical considerations on the nature of flame, Siemens came to the conclusion that if the full heating effect of a flame is to be obtained the flame ought not to play on the walls of a furnace, but must burn in the reverberatory furnace itself in the form of an enormous tongue. Until the year 1885 the flame was arranged so that it filled the furnace as nearly as might be; but the size of the flame has now been increased, and the success attained has been very remarkable. The temperature of the furnaces has been raised to such a height that the best fireclay bricks can scarcely resist it, and soft steel or soft iron can be produced with comparative ease. The extraordinary cheapness of the excellent material turned out by these furnaces is explained by the fact that the process makes it possible to melt together a mixture of old pig iron and old wrought iron.

We have now become acquainted with the development of the iron industry up to the present time.

The methods of extracting such other metals as copper, lead, nickel, etc., reduce themselves finally to converting the naturally occurring ores into oxides and reducing these by means of carbon.

The only two metals which call for special description are *zinc* and *aluminium*, the latter of which has only of late years been manufactured in quantity.

Their beautifully variegated copper roofs form part of the ornamentation of many old buildings, such as churches and castles. When we wish to cover spaces nowadays with metal plates—and this is done much more than it used to be—we almost always employ sheets of zinc, which are used chiefly because they are so much cheaper than copper, although it must be admitted that after a time they acquire an unpleasing grey colour. As it is only about a hundred years since the art of making zinc plates arose it was impossible to use zinc as a covering material in the olden days.

The reason why metallic zinc has been manufactured only in recent times is as follows. If a mixture of oxide of zinc and carbon is heated reduction certainly takes place with the formation of zinc and carbon monoxide, but the temperature whereat this reaction occurs is so high that the zinc, which is a comparatively easily volatilised metal, is vaporised. If zinc oxide is heated with carbon in one of the furnaces that were formerly used for reducing metals vapours of zinc are soon given off, but at the temperature attained these are at once burnt to oxide, so that no metallic zinc is obtained by this method of working.

It was only about the middle of last century that the extraction of zinc began in Europe—the Chinese seem to have practised the art at an earlier time—by heating zinc oxide and carbon, not in an open furnace, but in a retort, that is to say in a closed vessel, by means of a fire applied outside the vessel. The zinc vapour could not burn under such conditions, and the zinc was obtained in the form of metal which distilled from the retorts. It was not, however, until the beginning of the present century that the method of making zinc plates from the very brittle metal obtained in the way described was discovered. These zinc plates are employed nowadays for all sorts of purposes, and the discovery of a means of making them has caused the zinc industry to assume very large dimensions.

The properties of aluminium, the metal most recently introduced into daily life, are very different from the properties of those metals we have spoken of hitherto.

Aluminium is the most widely distributed of all metals, and is found in the largest quantities over the earth. The oxygen compound, the oxide, of this metal has long been called *alumina* by chemists, the name (and that of the metal itself) being derived from alum (Latin, *alumen*) because alum has long been known to be a compound, namely a double sulphate, of the metal in question (cf. p. 145).

We also know that all the clays are silicates of alumina (see p. 226). Every brick is rich in this metal, and every potsherd would be the raw material—the ore—from which the metal might be obtained were alumina reducible by carbon in the way that other metallic oxides are reduced. But this is not the case, for that method is altogether barred in this instance, as indeed might be expected from theoretical considerations. The reduction of their oxides is not the only method whereby metals can be prepared in the laboratory. There are other methods, some of which are very complicated, and it was by one of these that aluminium was first procured in 1827. Attempts have been made uninterruptedly since the beginning of the fifties to apply some one of the laboratory methods on the large scale.

The first experiments which were conducted with large quantities of material were put on foot by Napoleon III. It was the time of the Crimean war, and he hoped to be able to use the very light metal as armour for the soldiers. These investigations led to improvements; nevertheless aluminium prepared by these processes, which employed only purely chemical methods, would have remained difficult to obtain and very costly. But it suddenly became possible to obtain very large quantities of an agent that had been used for long in the laboratory in the production of metals, but had been very expensive until about that time; this agent was electricity.

Notwithstanding its costliness electricity had been employed for many years in the technical separation of certain metals from solutions, but only when the object was to coat other metals with those that were electrically deposited. Such a process is called *electro-plating.* Large quantities of silvered goods have been prepared by this process since the fifties; and for that purpose the process is not expensive. The art of depositing a compact coating of one metal on another by the electric current was discovered almost simultaneously in 1839 by Jacobi in St. Petersburg and Spencer in England.

We should say a word about the historical development of the subject. The action of electricity on chemical compounds was investigated many years ago. Priestley, in 1775, announced that the fire (for that was the name used in those days) produced by frictional electricity decomposed ammonia gas. We know that ammonia is a compound of nitrogen and hydrogen (see p. 32); if electric sparks are allowed to pass through that gas a mixture of nitrogen and hydrogen is produced, after a time, in place of the ammonia. No one at that time could have imagined that after about a hundred and twenty years this observation would place a new metal at the disposal of mankind.

In 1782 the discovery was made that the electric fire could decompose water into its constituents hydrogen and oxygen, and in 1800 it was ascertained that not only frictional electricity, but also the galvanic current, which had been discovered ten years before that time, could do this.

As it was not very difficult to obtain electric currents by the use of batteries, the action of the current on chemical compounds was further investigated, and in 1806 the extraordinarily light metal *potassium*, and soon afterwards also the metal *sodium*, were obtained by electrolysis.

And in this way chemists became acquainted with quite new light metals which have such affinity for oxygen that they burn when they are thrown on to water; they do this by eagerly withdrawing oxygen from the water and combining with it, and the heat produced in this process is so great that the hydrogen, which too is set free from the water, takes fire in the air and causes the metal to burn also.

There seems to be no practical application for these metals, potassium and sodium, in ordinary life. But it is otherwise with aluminium, with which we are specially concerned at present; for aluminium is a very light metal, yet it is quite unchanged when exposed to water or the air, and therefore it is of practical utility.

The preparation of aluminium was accomplished by the aid of electricity in the following way, after a quite incredible number of attempts that ended in failure. Alumina is thrown into a melted mixture of cryolite (see p. 223) and fluorspar, and an electric current is passed into the fluid mass; the current decomposes the alumina into its constituents aluminium and oxygen, and in this way the problem of the extraction of aluminium is solved.

LECTURE XII.

Alloys: Coinage.—Bronze.—Patina.—Brass.—Tombac.—Talmi gold.—Nickel silver.—Britannia metal.—Type metal.—Nickel steel.

Alkaloids: Methane.—Acetylene gas.—Benzene.—Pyridine.—Coniine.—Quinoline.—Kairine.—Antipyrin.—Phenacetin.—Narcotine.—Chloral.—Ether.—Hoffman's drops.—Chloroform.—Antiseptics.—Iodoform.—Carbolic acid.—Corrosive sublimate.—Salicylic acid.

Metals are used not only by themselves, but *alloys* are formed by melting together several metals, and the properties of some of these alloys render them more valuable for certain purposes than their single constituents. For instance, those particular metallic alloys which are used for making coins pass through our hands every day. Pure gold, like pure silver, is so comparatively soft that both would wear away too quickly in commercial transactions. Older coins would soon fall off in their metallic value compared with those newly coined. But this happens only to a very small extent with the coins that are now used, inasmuch as copper is mixed both with the gold and the silver employed for coinage, for experience has shown that a sufficiently hard alloy is thus produced. The alloy of which German gold coins are made consists of 900 parts of gold and 100 parts of copper melted together. As 0·3584 gram of gold forms the coinage unit, under the name of *a mark*, a 10-mark piece weighs 3·982 grams (3·584 grams gold + 0·398 gram copper). One kilogram of gold is worth 2,790 marks. German silver coinage is made from an alloy of 900 parts of silver and 100 parts of copper, and 200 marks are coined from 1 kilogram of silver. No heed is taken of the intrinsic value of the silver, nor of the fluctuations in this value, for gold is the standard. One kilogram of silver is at present worth about 90 marks. The German nickel coins are struck from an alloy of 1 part of nickel with 3 parts of copper, and in a 10-pfenning piece there are 1 gram of nickel and 3 grams of copper. The German bronze coinage alloy consists of 95 parts of copper, 4 parts of tin, and 1 part of zinc, and 300 2-pfenning pieces or 500 1-pfenning pieces weigh 1 kilogram.*

The mention of the bronze coinage leads naturally to the consideration of bronze and brass.

Bronze † is a mixture of copper and tin in which the copper always preponderates. It is the most ancient of all known mixtures of metals. Most investigators are of opinion that all the metallic utensils that men used before the discovery of a method for extracting iron were made of bronze; hence it is customary to speak of *the bronze period*, which a few people think was preceded by a period of copper.

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* The English gold coinage alloy consists of 11 parts of gold and 1 of copper; the silver coinage alloy of $\frac{37}{40}$ of silver and $\frac{3}{40}$ of copper; and the bronze coinage alloy of 95 parts of copper, 4 parts of tin, and 1 part of zinc.—TR.

† According to the most recent investigation the word "bronze" is a contraction derived from *æs Brundusium*—that is, metal from Brundusium (the modern Brindisi); just as *æs Cyprium*, metal from Cyprus, is the origin of the word "copper."

Bronze is still manufactured in very large quantities, and it is employed for all sorts of purposes. Not only as church bells does it send its warning sound to the ears of the solitary man, but also in the form of cannons, which only began to be made of cast steel a generation ago, it has an impressive word to say in determining the fates of the peoples. Most lengthy investigations have been conducted by different states all over the world with regard to the bronze alloys, in the hope of finding the absolutely best alloy for casting cannon, and the books that contain accounts of all that can be said or thought about the bronzes would fill a library. The remarkable ease with which bronze can be cast makes it a most suitable material for producing works of art; and the great equestrian statues, for instance, show how safely it can be manipulated for such purposes.

Such works of art do not suffer hurt by long exposure in the open air, but they take on that beautiful rich rust which is called *patina*.* It is characteristic of patina that along with its malachite-green colour it has a metallic character; the peculiar metallic lustre appears through the colour. In this respect it is entirely different from any colouring material; for if a statue is made lustrous by a coat of varnish, for instance, the gloss is altogether superficial and does not come from within.

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* If much coal is burnt near to bronze statues the sulphurous acid that is sent into the air (see p. 193 *note*) along with the soot, which in itself is hurtful, so greatly retards the formation of patina that in many cases none gets formed.

Copper alloys with zinc just as readily as with tin. There is a great demand for *brass*, which is the product of mixing copper and zinc. Although zinc was not isolated until last century (see p. 293), yet the observation had been made long before that time that the metal obtained by smelting copper ores was yellow, and not red, when certain other ores were added before smelting; these other ores were called *cadmia* by the ancients, and at a later time the name *calamine* was given to them. We know now that the substances called *cadmia* or *calamine* were ores of zinc. Aristotle, about 330 A.D., tells that a kind of copper was found in India which could be distinguished from gold only by its taste; for whereas it was very pleasant to drink out of golden vessels, all vessels that contained copper had a disagreeable metallic taste. Aristotle recommended this means of distinguishing the two metals as an analytical method very suitable for the time.*

Brass can be made to resemble gold very closely by using suitable quantities of the constituent metals; and various articles made of this alloy, which is known as *tombac*, come into the market. The addition of some lead produces a colour which very closely resembles that of gold, but the product is not very lasting as it soon oxidises in the air. By covering this alloy, or tombac, with a little gold the substance known as *talmi gold* is produced.

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* He also relates that the Mesynœcians, a people living towards the north, made copper yellow by melting it with a certain earth, which must have been an ore of zinc. Some would derive the [German] word *messing* [= brass] from the name of that people; others say it comes from *möschen* or *maischen*, an older form of *mischen* [to mix]; and the brothers Grimm derive it from *massa*, a word used in the Middle Ages to express an unmelted lump of metal.

We should not pass over "*cuivre poli*," although that substance is going out of fashion. It is something between brass and bronze, and may be described either as a bronze rich in zinc, or as a brass poor in tin; it is nearly as cheap as brass—at present the cost of zinc is something less than a fourth of that of tin.

Nickel silver is produced by melting together copper, zinc, and nickel. This alloy played an important part from 1820 until about 1860; but it has been driven into the background by the introduction of silver electroplated goods. It was at first customary to strongly plate goods made of nickel silver. Cheaper white metallic mixtures were, however, soon introduced as the material to be plated—for instance, *Britannia metal*, which is produced by melting together 90 parts of tin and 10 parts of antimony; but this in turn has been replaced by yet cheaper materials.

In conclusion we must mention *type metal*, which is an alloy that we certainly do not often have an opportunity of seeing, although it serves to multiply our intellectual and spiritual nourishment. Lead is the chief constituent of this alloy; and to this are added antimony and a little tin and other similar metals. It is unfortunate that no one should have been able to produce an alloy suitable for use in printing without putting lead into it, because if this were done a final stop would be put to the serious cases of chronic lead poisoning which are not uncommon among compositors.

We have now seen what new valuable properties can be given to such very useful metals as copper, zinc, and others by alloying them. Iron, which we considered in great detail, is an exception in this respect. All the efforts made to improve the properties of iron by mixing it with other metals were without result until recently. But success certainly seems to have come at last, especially in increasing the hardness of steel by mixing it with a little nickel; at any rate very durable gun barrels have been manufactured of late years of the alloy known as *nickel steel*, and as it has also been used for making armour plate for men of war great expectations have been formed of its usefulness notwithstanding its high price.

Everything that has been brought forward in these lectures up till now has been concerned with knowledge which either is or can be applied to the advantage of mankind in general. We picture mankind to ourselves as a whole constantly striving to advance and unrestricted by the conditions of the time. But chemistry has also for long sought to place its results at the services of the individual who comes, lives, and departs, and who during the short space of his life is too often subject to sickness and laid low by illness.

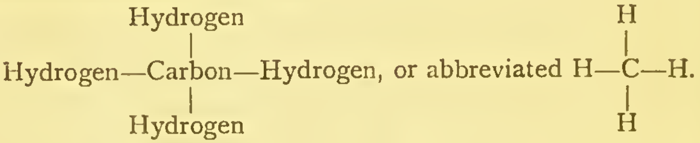
An older period in the history of chemistry is distinguished as the time of the *iatro*, or medical, chemists. But the advances made in this direction, as in so many others, at the beginning of the present century put into the shade all that had gone before.

The first step in this direction was the discovery of the *alkaloids*, which is the name given to certain substances of an alkaline character that are present in plants. It was supposed until that discovery was made that only acids, such as tartaric and citric acid and the like, and neutral substances, such as sugar and starch, could be obtained from the vegetable kingdom. But in investigating certain medically active drugs in 1803, Derosne discovered a substance with an alkaline reaction to which he gave the name of *opium salt.* This result struck him as so remarkable that he speaks of a "*matière vegeto-animale toute particulière.*" It was not until 1817 that pure *morphine,* an impure form of which constituted the opium salt of Derosne, was prepared and was finally proved to be a vegetable substance capable of combining with acids in the same way as a true base.

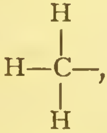
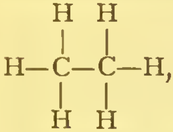
I need not now enter into details concerning the value of such an alkaloid as *quinine* as a febrifuge, or of *morphine* as a sleep-giver, or of *atropine* for opening the pupil of the eye, or of *cocaine* as a local anæsthetic or a kind of chloroform active only at one spot, or of similar alkaloids which to an ever increasing extent serve to alleviate and heal the troubles of suffering humanity. It is true that before the alkaloids themselves were known the drugs in which they occur were used as medicines with more or less success. But the alkaloids are often mixed in these drugs with so many other substances which modify their especial activity that the action of the alkaloid may sometimes be almost entirely suppressed. This is the case, for instance, with morphine as compared with opium taken directly from the plant, and from which morphine is extracted. The action of opium as a whole makes it useful for certain purposes, but not for employment as a sleep-producer.

The chemical investigation of these alkaloids shows, as we might expect, that the atomic complexes of which they consist are very far from being simple. We have already learned (see pp. 24 and 66, 67) that in order to have clear conceptions about a chemical compound it is not enough to know the number of atoms which build up the compound, but that we must also disentangle the atoms and discover how they are connected with one another. It is only when this problem has been solved—and even a layman will understand how extraordinarily difficult such a problem may be—that attempts can be made in the laboratory to reverse the procedure, and that the task of building up artificially such an atomic complex from the single atoms—that is, of synthesising the natural product—can be entered upon.*

The hydrocarbon which is called methane or marsh-gas is composed of a single atom of carbon and four atoms of hydrogen—thus



$$\begin{array}{c}\text{Hydrogen}\\ | \\ \text{Hydrogen—Carbon—Hydrogen}\\ | \\ \text{Hydrogen}\end{array}\text{, or abbreviated }\begin{array}{c}H\\ | \\ H-C-H.\\ | \\ H\end{array}$$

Now we know (pp. 23, 24) that all the compounds of organic chemistry may be regarded as derived from this hydrocarbon by supposing that other atoms, or atomic complexes, are substituted for the hydrogen atoms of methane, one monovalent residue taking the place of another monovalent residue, or a divalent taking the place of a divalent, or a trivalent the place of a trivalent residue. The group  $H-\underset{H}{\overset{H}{C}}-$, for instance, is a monovalent residue; if this combines with itself we have  $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$, which is the hydrocarbon C_2H_6, and so on.

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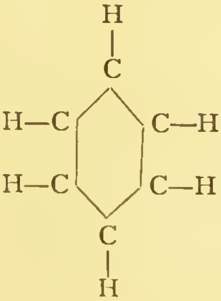
* It is only about forty years since the problem of building up, from atoms of carbon, hydrogen, and oxygen, ordinary pure spirit, which is a comparatively simple substance—its composition being expressed (see p. 87) by the formula C_2H_6O—was solved approximately in the laboratory. The alcohol that is made in the laboratory is, however, enormously more expensive than that which is obtained by fermentation.

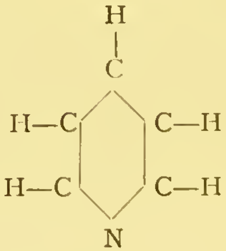
We can think of these chains of carbon atoms as lengthened to any extent (see p. 24), and also as branching out and even as returning upon themselves in the form of rings. Atomic complexes with six atoms of carbon are especially ready to form such an arrangement, and a ring of this kind shows an astonishing stability and a power of withstanding the attack of chemical reagents. As it is inconvenient always to draw circular figures, the custom has been adopted of drawing straight lines between the six carbon atoms, whereby the circle becomes a hexagon, a figure which is constantly met with in chemical literature.



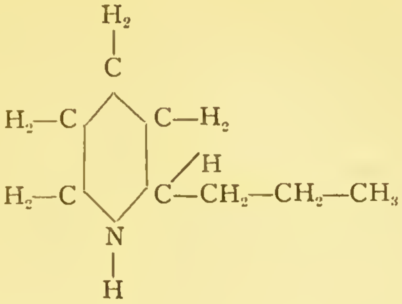
The hydrocarbon represented by the above scheme is the most simple imaginable under the conditions laid down. It is composed of six carbon atoms and six atoms of hydrogen; its formula is therefore C_6H_6. This hydrocarbon was discovered in 1825; the name *benzene* is given to it because it was soon afterwards obtained from *benzoic acid.* The conception of the six carbon atoms united in the form of a ring was developed by Kekulé in 1866.

Benzene is found in considerable quantities in coal tar; it is the mother substance of an enormous number of compounds, among which may be mentioned the aniline colours.

It has been known since the eighties that such ring-formed atomic complexes are constituted not only of atoms of carbon and hydrogen, but that the closing of the ring can be brought about by atoms of nitrogen also. Nitrogen is represented by the symbol N, and the simplest possible compound of this kind is C_5H_5N.

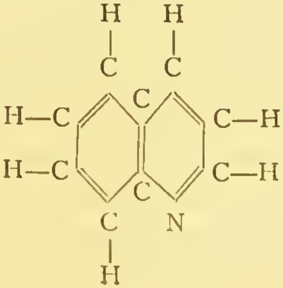


This compound is called *pyridine,* and it is found in coal tar. All the alkaloids, all those constituents of plants which have such a powerful action on the human organism, with a few exceptions, are derivatives of this compound. *Coniine,* for instance, is represented by the following atomic arrangement:



Coniine is the poison of hemlock. The method of the arrangement of the atoms in this substance was made known fully by Ladenburg; and this atomic complex, which up till that time had been built up only by nature in plants, was prepared artificially from pyridine by him in 1888.

The investigation of *quinine*, the most celebrated of all febrifuges, has not yet advanced so far, for quinine is put together in a much more complicated way than coniine, for example. But *quinoline* is easily obtained by splitting up quinine; and investigation has shown that quinoline is an atomic complex of two rings, and that in this compound a benzene ring and a pyridine ring are combined in the way represented by the following scheme:



It is not known as yet in what way the other atoms of quinine are connected to this complex. But we understand how to obtain quinoline in any desired quantities from coal tar derivatives. As a kilogram of quinine still costs about 80 marks [about 36*s.* per lb.], although the price has fallen considerably, the quinoline made from quinine was a very expensive substance; but a kilogram of this alkaloid can be bought to-day for less than 10 marks [about 4*s.* 6*d.* per lb.].

Regarding quinoline as what one might call the skeleton of quinine, the question suggested itself whether it would be necessary to clothe this skeleton with exactly the same atoms and atomic complexes as are contained in quinine in order to produce a substance with the qualities of a febrifuge; whether, if quinoline were transformed into an arrangement of atoms which, judging from the sum of our experience, would be suitable, the new substance, although only roughly approximating to the natural product, would resemble that product in possessing the power of reducing the bodily temperature of feverish patients.

After many trials the first artificial febrifuge made its appearance in 1881, and to it was given the name *kairine.* This substance has been replaced by more active bodies, and has long been forgotten, for since that time one new remedy has followed hard on the heels of another. When some knowledge of the special conditions had once been gained it was found that febrifuges could be prepared by putting together much simpler complexes of atoms than quinoline, and so it became easier to make such bodies in the laboratory.

The two substances which have proved to be the most practically useful are *antipyrin*, the atomic arrangement of which is very complicated, but which is not a derivative of quinoline, and *phenacetin*, a body with a comparatively simple arrangement of atoms.

We have already mentioned *morphine*, the introduction of which sleep-producing substance marked an epoch in the advance of therapeutical medicine, beginning with 1855, when Wood first used subcutaneous injections of the alkaloid, and so made its action more trustworthy.

Very many attempts have been made to find a suitable substitute for morphine because of the danger of that craving for it which is apt to follow the use of this drug. The first substitute was *chloral*, which, as its name suggests, bears some chemical relation to *chloroform*.

As time has gone on the number of these sleep-givers has become legion, for it has been found that substances of the most different kinds have this common property of producing sleep. Common alcohol is a sleep-producer; but the use of it in quantity is apt to be followed by unpleasant effects on the next day; and it is the same with many of the drugs that have been introduced recently. They produce sleep it is true, but they also produce many unpleasant effects; and for this reason the number of those that are of practical utility has greatly diminished, although it is still certainly quite large enough.

While the special purpose of these sleep-producers is to bring a sleep which as closely as possible simulates natural sleep, it is also well known that there are substances which produce so deep an unconsciousness that the most severe operations can be performed without the patient feeling any pain.

The first substance to be employed for this purpose was *ether*, a body that is easily prepared from alcohol. As ether is more conveniently obtained by distilling alcohol with sulphuric acid, it used to be called, and is still popularly called, *sulphuric ether*, although it does not contain a trace of sulphur, a fact which has been known for about a hundred years.

Ether was discovered about 1530 by Valentinus Cordus, who was Professor of Medicine at Wittenberg; and as early as 1541 its sleep-producing properties were known to Theophrastus Paracelsus Bombastus. In one of his books he says*: "This sulphur" (he means ether) "has an attraction for others; fowls take it and sleep for a time, waking again without any hurt." †

Three hundred years, unfortunately, passed before the full importance was appreciated of the experiment on animals made by Paracelsus, which proved that a deep sleep from which one awoke without harm could be produced by ether; and this is greatly to be regretted, for much of the pain that was borne for centuries by suffering humanity might have been alleviated, and operations might have been performed painlessly during all these three hundred years.

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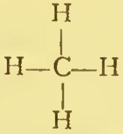
* "Zum andern hatt dieser Sulphur eine Süsse, dass jhn die Hühner all essen, vnd aber endtschlaffen auff ein Zeit, ohn schaden wieder auffstohndt."

† In another part of the same book Paracelsus extols ether as a remedy in all complaints. Hoffman, a clinical physician of Halle, about 1750 strongly recommended a mixture of three parts spirit with one part ether as a soothing and pain-stilling drug, and the mixture became a popular remedy under the name of *Hoffman's drops*.

An American chemist, Jackson, was the first fully to appreciate the importance of ether as an anæsthetic; in 1846 he recommended a dentist of the name of Morton to use it during operations on the teeth. The results were so remarkable that Warren, a surgeon, to whom they had been communicated, on October 17th, 1846, ventured to operate on a patient who had been made entirely unconscious by ether. The painless performance of surgical operations dates from that day.

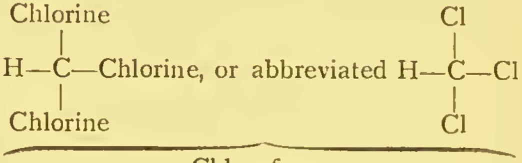
A search began at once to be made for specifics which should, if possible, be more suitable for bringing about the desired effect than the very explosive ether—the application of an actual cautery, for instance, was impossible when ether was employed; and as early as 1847 Simpson recommended chloroform, which has held the field, on the whole, since that time, although attempts have been constantly made to replace it by other and more efficient substances, or mixtures of substances.

Chloroform was prepared for the first time in 1831 by Liebig from chloral; it is manufactured to-day by the action of chloride of lime on alcohol. Chemically considered chloroform is a very simple substance. If three atoms of hydrogen in the hydrocarbon methane, with which we are now so familiar, are replaced by chlorine—and this can be done directly in the laboratory—we have chloroform produced.



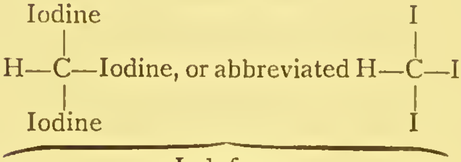
$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array}$$

Methane.



$$\underbrace{\begin{array}{c} \text{Chlorine} \\ | \\ H-C-\text{Chlorine} \\ | \\ \text{Chlorine} \end{array} \text{, or abbreviated } \begin{array}{c} Cl \\ | \\ H-C-Cl \\ | \\ Cl \end{array}}$$

Chloroform.



$$\underbrace{\begin{array}{c} \text{Iodine} \\ | \\ H-C-\text{Iodine} \\ | \\ \text{Iodine} \end{array} \text{, or abbreviated } \begin{array}{c} I \\ | \\ H-C-I \\ | \\ I \end{array}}$$

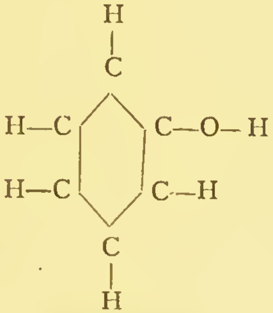
Iodoform.

In the above formulæ *iodoform* is placed beside chloroform to which it is closely allied. The abbreviated termination *form* is derived from the name *formic acid*; for the chemical constitution of these compounds is related to that of this acid, which, like them, is a derivative of methane very closely related to the parent compound.

In associating iodoform with chloroform we have passed, from the class of *narcotics*, to that of *antiseptics*, which have added the equable and regular healing of wounds to the painlessness wherein chloroform has enveloped the operations of the surgeon.

The world owes this improvement in the treatment of wounds, the greatest of its kind ever made, to Lister.

When the bacteria which are present everywhere in the air get into wounds they cause suppuration, and they often also bring about other bad results which are extremely dangerous and sometimes fatal. As it is impossible to shut out the surrounding air from contact with a wound, care has been taken, since this method was introduced about the middle of 1870, to dress the wound with some substance capable of killing the bacteria in the surrounding air. *Carbolic acid* is the substance that Lister used for this purpose. This compound is closely related to benzene; it contains only one atom of oxygen in addition to the constituents of benzene, and it has the following constitution:



Carbolic acid.

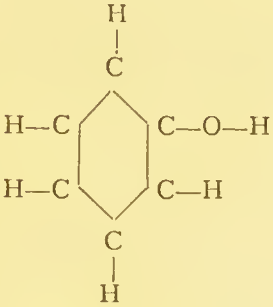
The great advance made by Lister will become more evident if we carry our thoughts back to the time of the Franco-German war—that is, to the beginning of 1870. At that time the universal custom was to pick lint from old linen, without taking due precautions, and also without any suspicion of the enormous number of infectious substances that might be brought into the wounds by a material prepared in that way and not subjected to disinfection. It is certain that the use of such lint caused the death of many who would have been saved to-day. Lint is not used now, for it has been replaced by linen bandages that have been treated with antiseptics and thus made entirely free from bacteria. And as everything that is allowed to touch a wound nowadays has been disinfected beforehand most of the wounds heal without festering. Severe operations are of course still attended with danger, but what used to be the commonest source of danger, namely, fever following the wound, is as good as abolished. And there are many operations that are practicable since the discovery of the antiseptic treatment which would certainly have been followed in former times by suppuration leading to death.

There is nowadays an enormous number of antiseptics, and carbolic acid has very many competitors; at the same time the need and the demand for antiseptics keep increasing because of the great advances that are being made in bacteriology and hygiene.

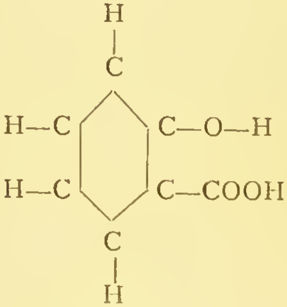
Iodoform, a substance already mentioned, has kept its position in the treatment of wounds in quite a wonderful way. The bacteriologists, however, often require a much more active and odourless substance, and for this purpose they generally make use of *corrosive sublimate*, which, chemically considered, is *chloride of mercury*. An aqueous solution of this compound has the most powerful antiseptic action even when it is greatly diluted; and were the compound not so extremely poisonous it would probably drive out almost all other antiseptics.

The public also require antiseptics which shall be quite odourless and tasteless and not in the least poisonous, for making foods keep well, for instance. *Salicylic acid* is on the whole most favoured for this purpose. This acid was first obtained in 1839 from the bark of the willow (*salix*), and the name then given to it to recall its origin has been retained.

The investigation of the arrangement of the atoms in this compound has shown that it is very closely related to carbolic acid, from which tar product salicylic acid can be prepared by replacing a certain one of the hydrogen atoms by an atomic complex called *carboxyl*.



Carbolic acid.



Salicylic acid.

Salicylic acid is now manufactured in very large quantities from carbolic acid by a method which has gradually been brought to the greatest perfection.

On the other hand, experience has shown that certain substances obtained from tar, which have very great antiseptic powers, can be used for all sorts of disinfecting purposes without being more than superficially purified, provided their other properties do not interfere with their use for these purposes; these substances can therefore be obtained at an extremely small cost.

And thus it is that work in the domain of chemistry advances without rest in ways of which we have learnt something, and everything that nature puts before us is tried in all directions and with the greatest earnestness, whether it be for the purpose of advancing pure science, or whether the aim be the good of mankind or that of the individual man. No longer, as in the olden days, is the whole covered with the mantle of alchemistic mystery, but it lies open, and investigation is shown to be justified; and, moreover, to the man who stands outside are given glimpses into this world of keen intellectual activity which must increase his general intelligence and quicken the special directions of his thought.

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